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AD-A206 708

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Analysis of Helicopter Environmental Data: Indianapolis Downtown Heliport, Wall Street Heliport Volume I Summary

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October 1988

DOT/FAA/CT-TN87/54, I

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U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

89

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN87/54, I	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ANALYSIS OF HELIPORT ENVIRONMENTAL DATA: INDIANAPOLIS DOWNTOWN HELIPORT, WALL STREET HELIPORT, VOLUME I SUMMARY		5. Report Date October 1988
		6. Performing Organization Code ACD-330
7. Author(s) Rosanne M. Weiss, John G. Morrow, Donald Gallagher, Mark DiMeo, and Scott Erlichman		8. Performing Organization Report No. DOT/FAA/CT-TN87/54, I
9. Performing Organization Name and Address Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. T0701R
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Rotorcraft Technology, ADS-220 Washington, DC 20590		13. Type of Report and Period Covered Technical Note May 1988
		14. Sponsoring Agency Code ADS-220 and AAS-100

15. Supplementary Notes

16. Abstract

During the summer of 1987 heliport environmental data were collected at the Indianapolis Downtown Heliport and at New York's Wall Street Heliport. The purpose of this data collection activity was to obtain measures of rotorwash in the heliport environment due to maneuvering helicopters, and to obtain pilot perceptions and observations concerning maneuvering and parking separation criteria. Ten wind vector transmitters were situated at various locations around the heliport in order to gather information to describe the rotorwash induced wind speed and direction changes. Pilot interviews were also conducted at these heliports.

Volume I of this report documents the results of this activity. It describes the data collection and analysis methodology and addresses technical as well as operational issues. It provides graphical descriptions of the heliport environment and of wind speed changes due to rotorwash from maneuvering helicopters, along with analysis of pilot responses.

Volumes II and III provide the plots generated from the New York and Indianapolis Heliport data.

The results of this study will be considered in future modifications of the Federal Aviation Administration (FAA) Heliport Design Advisory Circular (AC) 150/5390-2. (SCW)

17. Key Words Heliport, Tip Clearance, Rotorcraft, Rotorwash, Heliport Design Advisory Circular	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	56	

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

During the summer of 1987 heliport environmental data were collected at the Indianapolis Downtown Heliport and at New York's Wall Street Heliport. The purpose of this data collection activity was to obtain unobtrusive measures of rotorwash in the heliport environment due to maneuvering helicopters, and to obtain pilot perceptions and observations concerning maneuvering and parking separation criteria. The two measures of heliport environment recorded were wind speed and wind direction.

Ten wind vector transmitters were placed strategically around both heliports; four around the takeoff/landing area, four adjacent to the taxiway, and two near a parking location. The data collection activities at both Indianapolis and New York were conducted only during daylight hours under visual meteorological conditions. Observations of such information as visibility, surface wind conditions, type rotorcraft in operation, type maneuver being recorded, estimated hover heights, path of the aircraft, and times of sensor activation were noted for each operation recorded. Pilot interviews concerning maneuvering and parking separation were also conducted.

This report documents the results of this activity. The heliport environment, pilot perceptions, expert observations, and data collection, evaluation and analysis techniques are described. Data plots of wind speed and direction are included for each operation at both heliports. Pilot responses are discussed.

It was determined that, for the types of helicopters observed, high wind velocities due to helicopter rotorwash occur a very small percentage of the time during operations at a heliport. The wind velocity distributions are similar for the parking, taxiway, and takeoff/landing area data.

Pilot interviews indicated that approximately one-third of the pilots were comfortable with the criteria spelled out in the Heliport Design Advisory Circular (AC) 15/5390-2. Other issues concerning tip clearances under different wind conditions, hovering heights, and light conditions were raised and need to be studied further.

INTRODUCTION

PURPOSE.

The Federal Aviation Administration (FAA) Technical Center Heliport Parking, Taxiing, and Landing Area Criteria Testing was designed to provide data to validate the Heliport Design Advisory Circular (AC) 150/5390-2 current parking and taxi route separation criteria. This report reviews data collected at several public use heliports.

OBJECTIVES.

The following objectives were addressed by this portion of the tests:

1. To obtain unobtrusive operational measures of the heliport environment in terms of wind speed and direction changes due to rotorwash from maneuvering helicopters.

2. To obtain pilot input concerning heliport surface maneuvering and parking separation criteria, and to determine, via observation, the type of operations being conducted at the public use heliports.

BACKGROUND.

The focus of this portion of the test was on the issue of "measurements of maneuvering helicopter rotorwash in the heliport environment." The current FAA Heliport Design Advisory Circular states in relation to parking: "Parking may be accomplished on a paved or unpaved apron, a helipad, or a helideck... . Except for helipads and helidecks located in the Final Approach and Takeoff Area (FATO) or takeoff and landing area, the parking area shall be located such that parked helicopters are clear of the approach and departure surfaces and have at least 1/3 rotor diameter but not less than 10 foot (3 m) clearance from a takeoff and landing area or a fixed or movable object."

In relation to the taxi route: "A cleared right-of-way for taxiing shall be provided between a takeoff and landing area and a parking area... . The taxi route width shall be at least the larger of:

1. twice the rotor diameter of the largest helicopter which is expected to hover taxi, or

2. one and one-half rotor diameters of the largest helicopter which is expected to ground taxi, plus 14 feet (4m).

The centerline-to-centerline separation distance (between taxi routes) shall be at least the larger of:

1. one and one-half rotor diameters of the largest helicopter which is expected to hover taxi, or

2. one and one-quarter rotor diameters of the largest helicopter which is expected to ground taxi, plus 7 feet (2m).

When a hard surface taxiway is provided, it shall be centered within a taxi route and shall be at least twice the width of the undercarriage of the design helicopter."

This criteria was based on experience, tempered with engineering judgement. There is little actual environmental or flight data to validate it. It may or may not reflect the clearances actually needed or desired for surface operations by rotorcraft pilots. The issue of rotorwash impact on helicopter control and stability and its effect on required or desired separation criteria had not been previously addressed.

The data collected during this study was designed to measure rotorwash effects on the surface of operational heliports and obtain pilot perceptions of adequate separation for taxiing and parking operations at heliports. Expert observations of hover taxi heights and lateral deviations during each operation, as well as parking separation and environmental obstructions, were recorded.

METHODS

DATA COLLECTION.

LOCATIONS. The environmental data were collected at two operational heliports, the Indianapolis Downtown Heliport and New York's Wall Street Heliport. The Indianapolis data were collected over a 7-day period in August 1987 during the Pan American Games. The New York data collection trip took place over a 3-day period in September 1987, immediately following the opening of the Wall Street Heliport.

PROCEDURES. Ten Belfort Instrument Company 5-122 HD wind vector transmitters were used to collect wind data during rotorcraft maneuvers at these two heliports. These transmitters consist of two major elements: an upper section containing a wind speed generator attached to an airplane rudder shaped vane, and a fixed, vertical support and connector housing. The wind speed signal generator is housed in a weatherproof housing and is driven by a six-bladed propeller. The transmitter senses both wind speed and direction. It converts these measurements into two direct current (dc) voltages, one of which is proportional to both wind speed and the sine of the wind angle, and the other which is proportional to wind speed and the cosine of the wind angle. This information is output on a continuous basis. The only limitations are the speed of the computer used to record the data and the inertia of the propellor. The sensors were connected to an interface system which, in turn, provided input data to a Zenith personal computer (PC). The data collection rate was 0.667 hertz (Hz). The PC was programmed to read sine and cosine sensor values, sensor number, and time in a sequential chronologically ordered manner.

At both heliports, the ten wind vector transmitters were place strategically around the heliport. All sensors were positioned approximately 20 inches above the ground. Four sensors were placed around the landing/takeoff area. Four sensors were placed adjacent to the taxiway and two were placed near a parking location. At Indianapolis the two at the parking location were placed near one of the two hot refueling locations, while at New York they were actually placed one on each side of a parking spot on the parking barge. Sensor locations for each heliport are depicted in figures 1 and 2. Appendix A contains photos of the sensors at each heliport.

The data collection system was operational during daylight hours only at both locations. The weather was visual flight rules (VFR) with clear skies for the entire Indianapolis trip and for 3 of the 4 days in New York. On the fourth day at New York the weather was marginal VFR with rain and reduced visibility.

Measurements were taken of the distances between parking locations as well as of the distance each sensor was from its corresponding coverage area. See figures 1 and 2 for the actual locations. Aerial as well as ground photos were taken of the equipment and the heliport facilities.

PILOT INTERVIEWS. Between the two heliports, 50 pilots were interviewed. Questions were posed concerning their opinions about the minimal rotor tip clearances distances they feel comfortable with when hovering near obstacles and when maneuvering adjacent to parked helicopters. These issues were explored in reference to separation criteria as influenced by rotor downwash. Pilot comments about the heliport environment were also logged. Figure 3 is an example of the questionnaire used.

OBSERVATIONS. The observers were responsible for recording the following information for each heliport operation:

Visibility and winds
Type rotorcraft
Type maneuver, ground or hover taxi, approach or departure
Hover height
Path of helicopter during the maneuver
Times each sensor was activated

The observers activated the data collection system before the helicopter began maneuvering and stopped the system after the helicopter either left the area or shut down. Static data were collected prior to the maneuver and for 1 to 3 minutes following the maneuver.

When the helicopter passed near each sensor the observer marked the time on a heliport map along with hover height and observed path of the helicopter. Actual or estimated wind conditions and visibility were also logged. At Indianapolis the rotorcraft type was recorded and its gross weight was determined through pilot input; while in New York only the rotorcraft type was entered. Gross weight was estimated by the observer since, in many cases, the aircraft arrived, discharged cargo or passengers, and departed without shutting down.

ROTORCRAFT TYPES AND PILOT EXPERIENCE.

On the average there were almost 100 operations per day at the New York facility, while at Indianapolis there were approximately 16 per day. The test period at Indianapolis was during the Pan Am Games, thus, the number of operations per day was greater than normal. The higher volume of traffic at the New York Heliport was considered a normal everyday condition. Often the landing, taxiing, and parking areas were simultaneously in use at the New York facility, with seven or more rotorcraft parked on the barge and two rotorcraft at minimum collective pitch at the loading/unloading area. Simultaneous operations were only observed on occasion at Indianapolis.

Data were collected for various rotorcraft at both facilities under a variety of operating conditions. At Indianapolis 114 operations were observed, while 288 operations were observed at New York. Of those operations at Indianapolis, data were collected for nine different rotorcraft types. At New York ten different types were observed.

See table 1 for a breakdown of rotorcraft operations by type. Although the Indianapolis Heliport is ideally designed for wheeled landing gear helicopters, the majority of the helicopters observed using this facility were skid gear aircraft. The opposite is true at New York. The New York facility is ideally designed for skid type rotorcraft, but the majority of those observed were wheeled gear configured.

The majority of the pilots interviewed at both heliports had more than 3000 hours of flight time (see table 2). This indicates that most of the pilot input came from experienced pilots. This was particularly true for those pilots interviewed in New York where all could be considered high time pilots.

DATA PROCESSING AND ANALYSIS

ROTORCRAFT GROUPINGS.

The helicopters observed at these locations were grouped into three classes by weight. Table 3 presents the breakdown of those rotorcraft observed into the three weight classes.

GRAPHICAL AND TABULAR ANALYSIS.

All plotting done for this project was accomplished using a California Computer's Calcomp model 1051 drum plotter with FORTRAN software for the DEC's VAX 11/750 computer. The individual plots generated were divided into two types: wind direction with speed and wind direction with order of collection.

The wind direction and speed plots show vectors representing wind direction with a numerical value printed at the end of each vector indicating wind speed in knots. The second type plot shows the wind direction line with the numerical value indicating the order of data collection. Examples of these plots are found in the results section.

Plots of pilot responses in reference to comfortable maneuvering distances from objects as well as from aircraft were also produced using the Calcomp plotter. Histograms were produced on a PC using LOTUS 1-2-3 software. One set of histograms shows the percentage of actual observed windspeeds at each 5-knot interval for each approach and departure by helicopter weight class, and for each of three heliport surface locations: landing/takeoff, taxiway, and parking areas. A second set shows percentage of observed wind speed changes by 5-knot intervals. The percentages of wind direction changes by 10^{o} intervals for each surface location were also plotted.

TABLE 1. TYPE ROTORCRAFT AND NUMBER OF OPERATIONS

Aircraft Type	Indianapolis	New York
Aerospatiale Astar	17	42
Aerospatiale Twin Dauphin	0	2
Aerospatiale Twin Star	8	10
Agusta A109	0	9
Bell 222B	0	38
Bell 222UT	0	14
Bell Jet Ranger	12	58
Bell Long Ranger	15	49
Bell UH-1	29	0
Boelkow 105	2	14
Boelkow 117	10	0
Hughes/McDonnell Douglas 500	16	0
Robinson R22HP	5	0
Sikorsky S-76	0	52
Total	114	288

Note: 7 days of data collection at Indianapolis, 3 days at New York.

TABLE 2. PILOT EXPERIENCE

Indianapolis Downtown Heliport

Total Flight Time (hrs)	Number of Pilots
0-500	2
501-1500	3
1501-3000	2
> 3000	21

New York - Wall Street

Total Flight Time (hrs)	Number of Pilots
0-500	0
501-1500	0
1501-3000	3
> 3000	19

TABLE 3. OBSERVED ROTORCRAFT CLASSIFIED BY GROSS WEIGHT

≤3000 lbs	3000-7000 lbs	≥7000 lbs
Hughes 500	Astar	Bell 222B
Robinson R22HP	Augusta 109	Bell UT222
	Boelkow 105	Boelkow 117
	Jet Ranger	S-76
	Long Ranger	UH-1
	Twin Star	
	Twin Dauphin	

RESULTS

WIND SENSOR DATA.

All wind sensor data collected during the aircraft operations were corrected to account for sensor bias based on 0^{o} and 0 knots calibration. Volume II of this report contains all Wall Street Heliport wind sensor plots. Appendixes A to F contains the plots showing wind direction with order of collection, while appendixes G to L contain plots with wind direction and wind speed. Volume III contains similar plots for the Indianapolis Downtown Heliport data. Samples of these plots can be found in figure 4.

With exception of the takeoff/landing area sensors, the placement of the sensors at the Indianapolis Downtown Heliport were approximately one-half the distance from the center of their coverage areas than the corresponding sensors at the Wall Street Heliport. These sensor distances for all three areas at both the Wall Street Heliport and Indianapolis Downtown Heliport are presented in table 4.

TABLE 4. SENSOR LOCATIONS IN FEET FROM THE CENTER OF THE CORRESPONDING COVERAGE AREA

	Wall Street Heliport (ft)	Indianapolis Downtown Heliport (ft)
Takeoff/Landing Area	50	48-50
Taxiway Area	34-39	14-16
Parking Area	30	15

For this data collection activity, an operational period is defined as the time period from just prior to the aircraft's initiating a maneuver to the time when the aircraft either shut down or left the area.

Aircraft operating at the Wall Street Heliport during the data collection activity were representative of only two of the three weight classes. Figure 5 presents the histograms of observed wind speeds during operational periods for the three different sensor locations. Results are essentially identical for all three areas. The duration of an average approach operation for the 3000-7000 pound helicopters was 53 seconds. For the weight classes 3000-7000 pounds and greater than 7000 pounds, at least 65 percent of the approaches at Wall Street generated less than 10 knots of wind at all three surface locations where the sensors were positioned. For the 3000-7000 pound aircraft, high wind conditions (greater than 20 knots) were generated less than 10 percent of the time over all the approach operational periods. The average high wind conditions lasted less than 2 seconds per approach. With aircraft greater than 7000 pounds, the proportion of high wind conditions during these periods were larger, but still less than 25 percent of the time. For this class an average approach operation lasted 78 seconds, with the high wind conditions being observed a maximum of 7 seconds per approach period at the takeoff/landing area. However, it is unknown how long the aircraft was positioned in each area during any given approach. There is little difference in the distributions of recorded wind speeds for both classes of aircraft at all three surface locations.

Another measure of the effect of rotorwash is the changes in wind speeds which were observed during the operational periods. These changes were generated by comparing each wind speed measurement to the previous measurement. For extremely short time periods (less than 1 second per operation for both classes of helicopter) wind speed changes exceeded 20 knots during the operation. For the 3000-7000 pound class, 90 percent of the time changes in wind speed were 5 knots or less at all three locations, while at least 85 percent of the time changes were 5 knots or less for the 7000+ pound class aircraft. The distributions of velocity changes for the Wall Street Heliport approaches are plotted in figure 6.

Compared to the approaches, the departures show similar percentages of high wind occurrences (>20 knots) during operational periods for the taxiway area, and smaller proportion of higher wind conditions for the takeoff/landing and parking areas for the 3000-7000 pound class. The percentages at all three locations for the 7000+ pound weight class departures were lower than for the approaches, particularly for the taxiway and takeoff areas. Figure 7 presents the histograms for actual wind speeds during departure operations at Wall Street. However, compared to the approaches the average duration of a departure operation was from 20 to 40 seconds longer; 73 seconds for the 3000-7000 helicopters, and 117 seconds for the 7000+ pound helicopters. These high wind conditions were observed for less than 3 seconds during each 3000-7000 pound aircraft departure and for less than 6 seconds per 7000+ departure period. As with the approaches, it is not known how long the helicopter stayed at each location during the departure.

The distribution of the wind speed changes during operational periods for departures are similar to the distributions for the approaches. These distributions are plotted in figure 8.

Since loss of lift is a function of wind direction changes, changes in wind direction were also examined as a measure of rotorwash effect. As with the speed changes, these changes were calculated by comparing each measurement of direction with the previous measurement.

For the 3000-7000 pound helicopter approaches, a 30° or greater shift in wind direction was observed the largest percentage of the time (23 percent) at the takeoff area. The parking and taxiway areas and all three areas for the 7000+ pound helicopters had occurrences of 30° or greater shifts less than 12 percent of the time.

For departures, the larger shifts (equal to or greater than 30°) occurred no more than 16 percent of the time at all three locations for both classes of aircraft. The plots in figures 9 and 10 show the distributions of wind direction shifts.

Indianapolis wind speed data for landing operations showed greater occurrences of the high wind conditions (>20 knots) at all three locations. Data plots for two of the three classes of aircraft (<3000 pound and 3000-7000 pound) show similar wind speed distribution results for approach operations at each of the three sensor locations. An average approach for the less than 3000 pound class lasted 54 seconds, while for the 3000-7000 pound class it lasted 52 seconds. During these operations at Indianapolis at least 70 percent of the operations generated speeds less than 20 knots. The average approach for the 7000+ pound aircraft was 65 seconds. For this class of aircraft a larger proportion of wind speeds greater than 20 knots were observed. Distributions of wind speed changes at Indianapolis were more variable than at the Wall Street Heliport with a larger proportion greater than 20 knots. These distributions are plotted in figures 11 and 12.

The larger occurrences of higher wind speeds at the Indianapolis Downtown Heliport, when compared to the Wall Street Heliport, particularly for the parking and taxiway areas, are due to the sensor locations. At the Wall Street Heliport the sensors placed around the taxiway and parking areas were approximately twice the distance from the centerline than at Indianapolis. Also, hover heights at Indianapolis were generally higher than those at New York. Thus, the higher power requirements at Indianapolis resulted in a larger proportion of higher wind speeds being recorded.

The Indianapolis Downtown Heliport departure data, plotted in figure 13, show similar distributions of high winds for all three locations. As with the approach data, the distributions for wind speed changes are comparable. The average departure for aircraft in the less than 3000 pound class lasted 33 seconds. Greater than 70 percent of the wind speed changes were from 0 to 10 knots. The average duration for the 3000-7000 pound and 7000+ pound helicopter departures was 49 to 51 seconds, with at least 60 percent of the wind changes from 0 to 10 knots. The wind speed changes are plotted in figure 14.

Large shifts in direction (30° or more) were seen more frequently during approaches at the Indianapolis Downtown Heliport for all three classes of helicopter at all three locations. At least 43 percent of the wind shifts were 30° or more. Figure 15 shows the plots of these shifts for the Indianapolis approaches. For Indianapolis departures these large shifts in direction occurred a similar percentage of the time as the approaches, at least 44 percent of the time. These shifts are plotted in figure 16.

PILOT INTERVIEWS.

Twenty-eight pilots from Indianapolis and 22 from New York's Wall Street were asked for their opinions regarding their perception of safe maneuvering distances between objects and other aircraft. Responses concerned rotorwash effect when referenced to maneuvering near aircraft with main rotor blades unsecure. Table 5 shows the breakdown of the number of pilots interviewed by helicopter size.

TABLE 5. NUMBER OF PILOTS INTERVIEWED BY WEIGHT CLASS

Helicopters <3000 lbs	Helicopters 3000-7000 lbs	Helicopters >7000 lbs
4	24	22

In reference to their perceived comfort levels maneuvering near objects, pilots of helicopters in the <3000 pound category responded with distances ranging from 20 to 40 feet. For those flying helicopters in the 3000-7000 pound category the distances varied from 4 to 100 feet. The >7000 pound helicopter pilot responses ranged from 5 to 80 feet. These responses are listed by weight class in table 6. Figure 17 graphically presents these data with respect to rotor diameter. For the aircraft being flown, approximately 70 percent of the pilots responding to the question about tip clearances from an object expressed preferences for less than or equal to 1 rotor diameter.

When asked their perceptions about maneuvering distances from other aircraft, the pilots flying the less than 3000 pound gross weight helicopters answered with distances varying from 20 to 40 feet. Pilots flying helicopters in the 3000-7000 pound weight class gave figures from 8 to 100 feet, while those in the >7000 pound category responded with distances from 4 to 150 feet. Table 7 lists these pilot responses by weight class. Figure 18 depicts these responses in reference to rotor diameter. The percentage of responses for this question are similar to the previous one. Seventy-two percent of those responding stated comfort levels less than or equal to 1 rotor diameter.

In general, pilots felt the distance from objects depended on the stability of the object and the pilot's familiarity with the area as well as the winds conditions. Other pilots based their blade tip clearances on the distances recommended in their respective aircraft operators manual.

Many additional comments were received addressing concerns specific to either the Indianapolis or New York Wall Street Heliports.

OBSERVATIONS.

Observations were made at both heliports indicating that, although both are operating with or using procedures that are not specifically addressed in Federal Aviation Regulation (FAR) Part 77, the rotorcraft are being safely maneuvered in and out of these facilities. At Indianapolis, curved approaches/departures were routinely performed. Also, at Indianapolis the taxiway is noticeably higher than the surrounding terrain, which is very uneven. This irregular, uneven terrain appears to influence hover height depth perception during hover taxiing, leading to a large variability in hover heights. Yet, safe maneuvers are continually being conducted.

At Wall Street there was no real controllable approach/departure surface. The navigable channel runs close to the end of the pier. Therefore, it was not

TABLE 6. COMFORTABLE MANEUVERING DISTANCES TO OBJECT BY WEIGHT CLASS

(Also see figure 17)

Distance	≤3000 lbs	3000-7000 lbs	≥7000 lbs
3-9 feet		3	3
10-19 feet		3	7
20-29 feet	1	1	
30-39 feet		1	
40-49 feet	2		
50-100 feet		5	4
1 rotor radii		3	3
1 rotor diameter	1	1	2
1.5 rotor diameter			2

TABLE 7. COMFORTABLE MANEUVERING DISTANCES TO OTHER AIRCRAFT BY WEIGHT CLASS

(Also see figure 18)

Distance	≤3000 lbs	3000-7000 lbs	≥7000 lbs
3-9 feet		1	3
10-19 feet		5	6
20-29 feet	1	2	2
30-39 feet		1	
40-49 feet			
50-100 feet	2	3	2
>100 feet			2
0.33-0.5 rotor diameter		3	1
1 rotor diameter	1	4	1
1.5 rotor diameter			1
2 rotor diameter			2

uncommon to observe water vessels ranging from tugboats and yachts to military vessels and oil tankers maneuvering at varying distances off the end of the pier. Some of these vessels certainly penetrate the existing Part 77 approach/departure surfaces of the heliport. These penetrations were caused by both the antennas mounted on some of the craft and the superstructures of others. However, New York pilots did not perceive this as a problem.

CONCLUSIONS

From the pilot questionnaire data the following can be said:

1. Although the subject pilots were generally high time pilots (greater than 3000 hours), only 30 to 36 percent reported that they were comfortable with the helicopter/object and helicopter/helicopter separations recommended in the Federal Aviation Administration (FAA) Heliport Design Advisory Circular (AC) 150/5390-2 (0.33 rotor diameters but not less than 10 feet).

2. No differences were observed in the distributions of wind velocity for the three locations: parking, taxiway, and takeoff/landing areas.

3. Wind velocities greater than 20 knots occurred for at most 7 seconds per operation at Wall Street and 12 seconds at Indianapolis. These durations correspond to a maximum of 25 percent of a total operation period at Wall Street; and at most, 34 percent at Indianapolis. The significance of these wind velocities in relation to other aircraft, however, is dependent upon the weight class and type of aircraft operating in the vicinity.

4. The pilot interviews and observations raised a number of other issues that need to be considered. These specific issues were:

   a. What rotor tip clearances do pilots recommend when maneuvering/parking helicopters under head, tail, and crosswind conditions; and how do these recommended tip clearances compare to actual performance under these conditions?

   b. What rotor tip clearances do pilots recommend when maneuvering helicopters near both secured and unsecured aircraft and objects; and how do these recommendations compare to actual performance?

   c. At what hover heights are pilots comfortable during taxiing operations?

   d. What type surface markings do pilots prefer for safe parking and maneuvering operations?

Tests and pilot interviews to examine items 4a, 4c, and 4d were subsequently conducted and the results will be contained in the Heliport Maneuvering Tests report, DOT/FAA/CT-TN88/30. Item 4b still needs to be investigated.

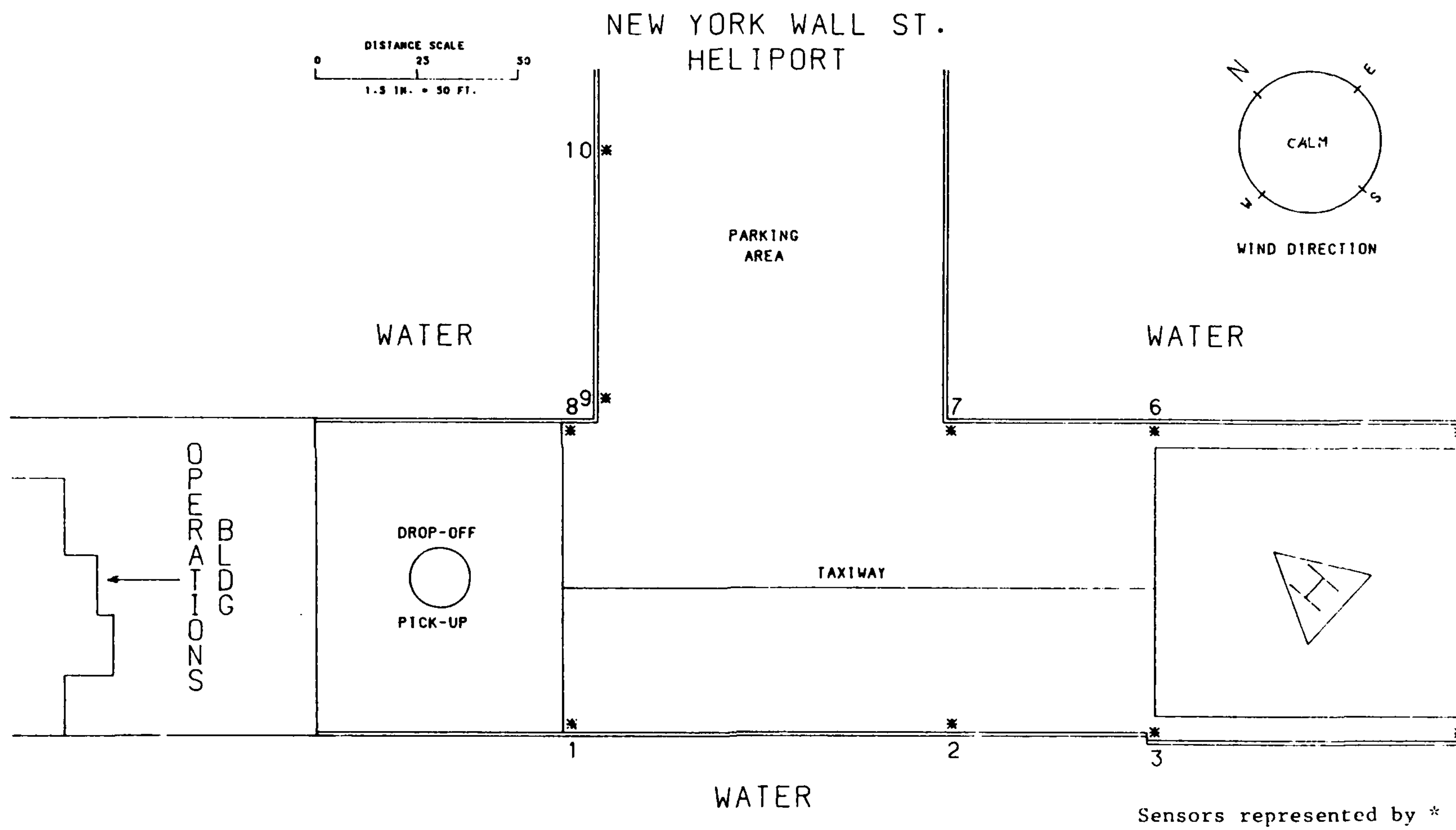


FIGURE 1. SENSOR PLACEMENT AT INDIANAPOLIS

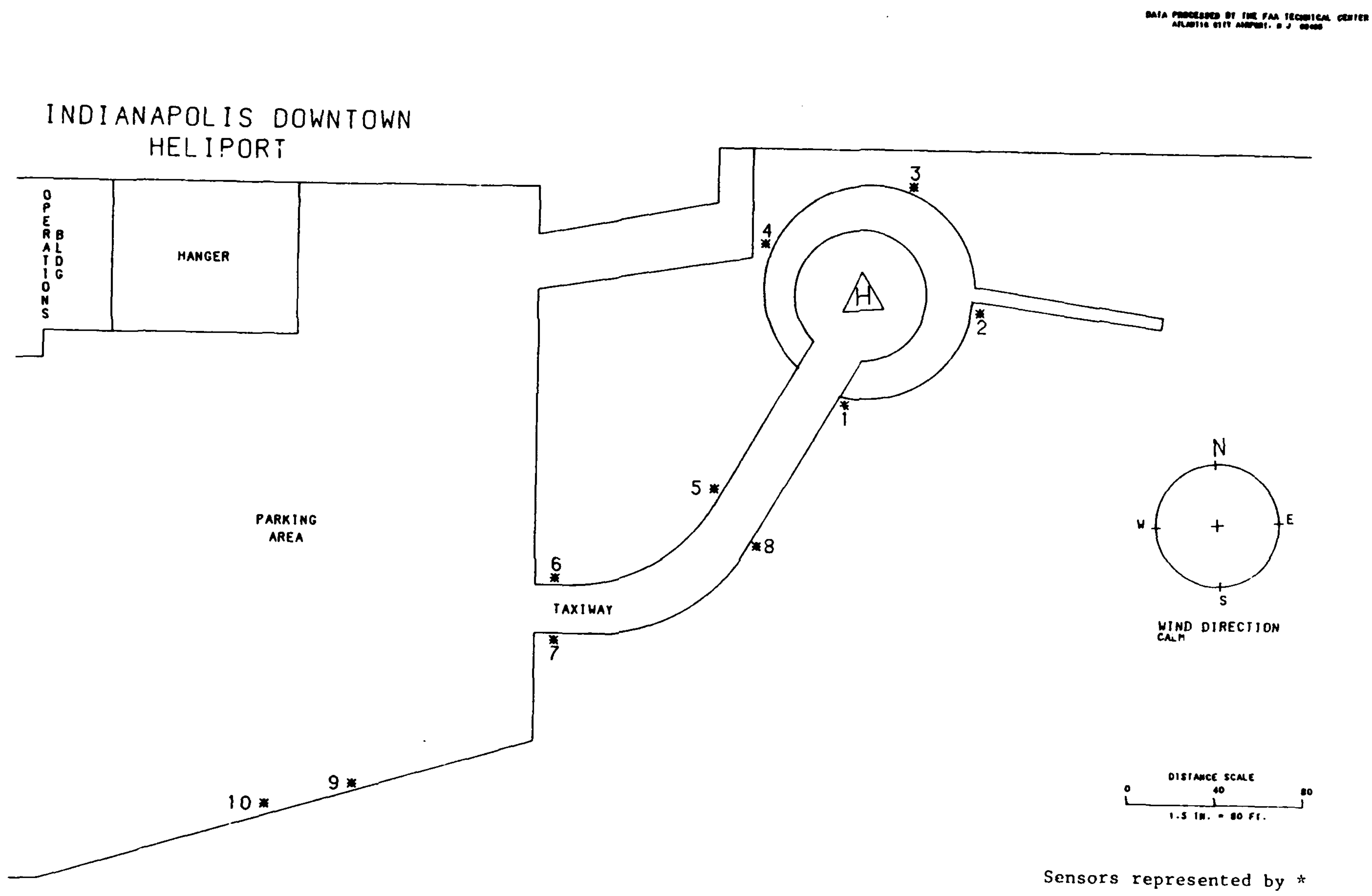


FIGURE 2. SENSOR PLACEMENT AT NEW YORK

LOCATION: DATE:

WIND CONDITIONS: VISIBILITY:

TYPE AIRCRAFT: GROSS WEIGHT:

KIND OF OPERATION:

____ GROUND TAXI

____ HOVER TAXI

____ LANDING

____ TAKEOFF

____ PARKING

____ HOVER IN

____ GROUND TAXI IN

____ TOW IN

HOVER HEIGHT: LATERAL PLACEMENT:

ABLE TO TALK TO PILOT?: ____ YES ____ NO

IF YES:

PILOT FLIGHT TIME:

MINIMAL DISTANCE PILOT WOULD FEEL COMFORTABLE HOVERING/TAXIING

NEAR OBJECTS?

NEAR OTHER AIRCRAFT?

COMMENTS:

FIGURE 3. SAMPLE QUESTIONNAIRE USED

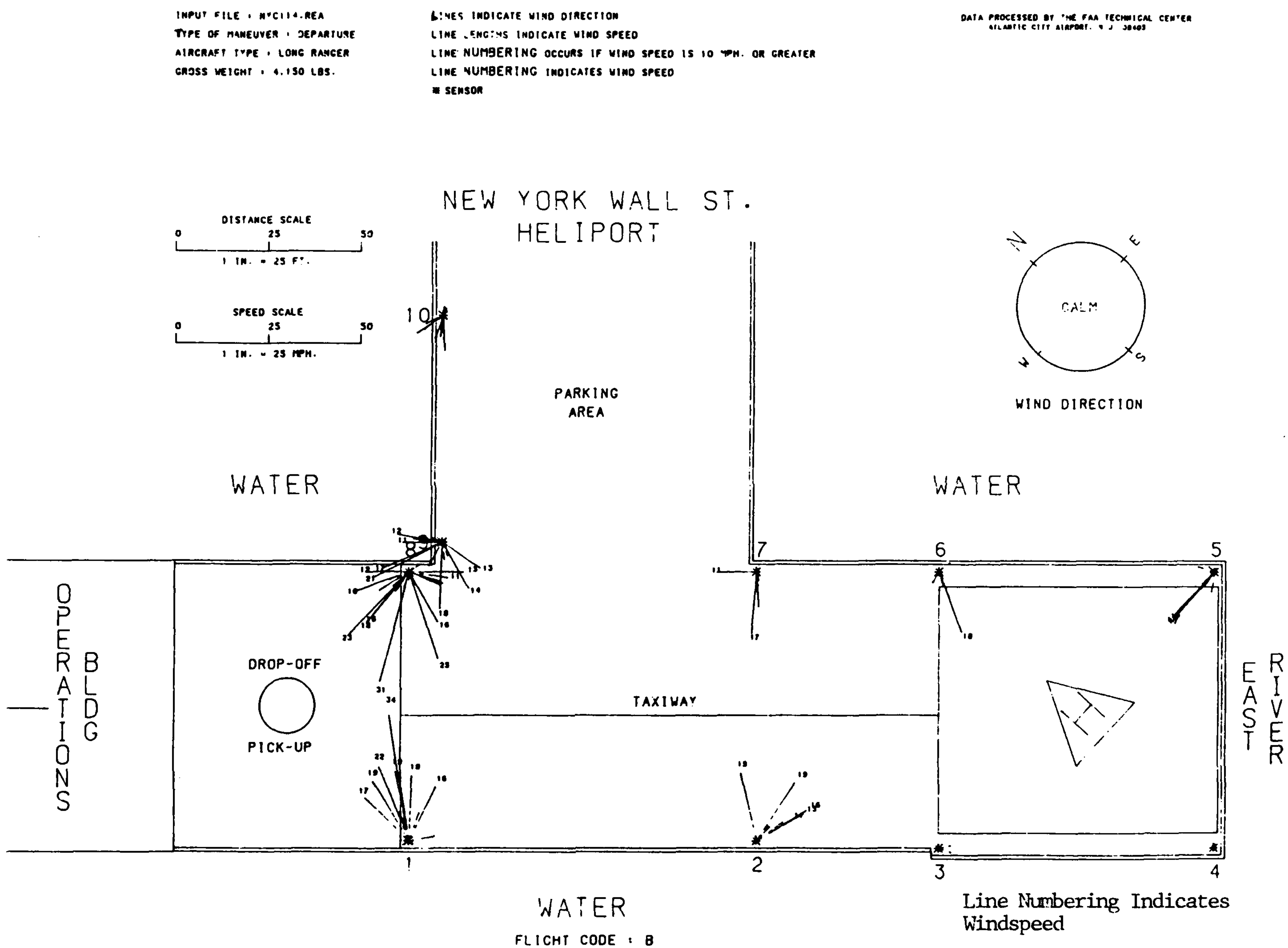


FIGURE 4. SAMPLE WIND DIRECTION PLOTS (SHEET 1 OF 2)

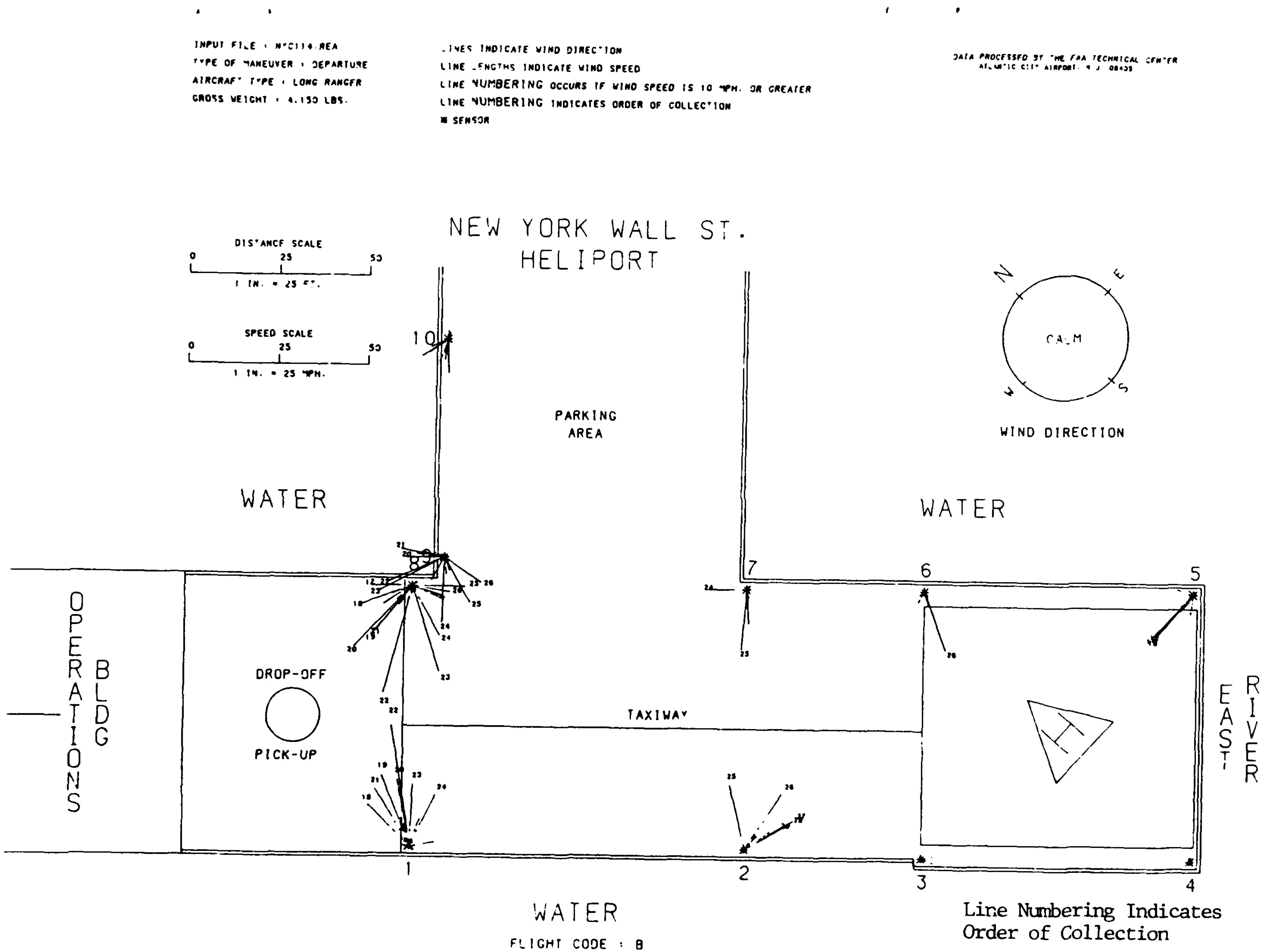
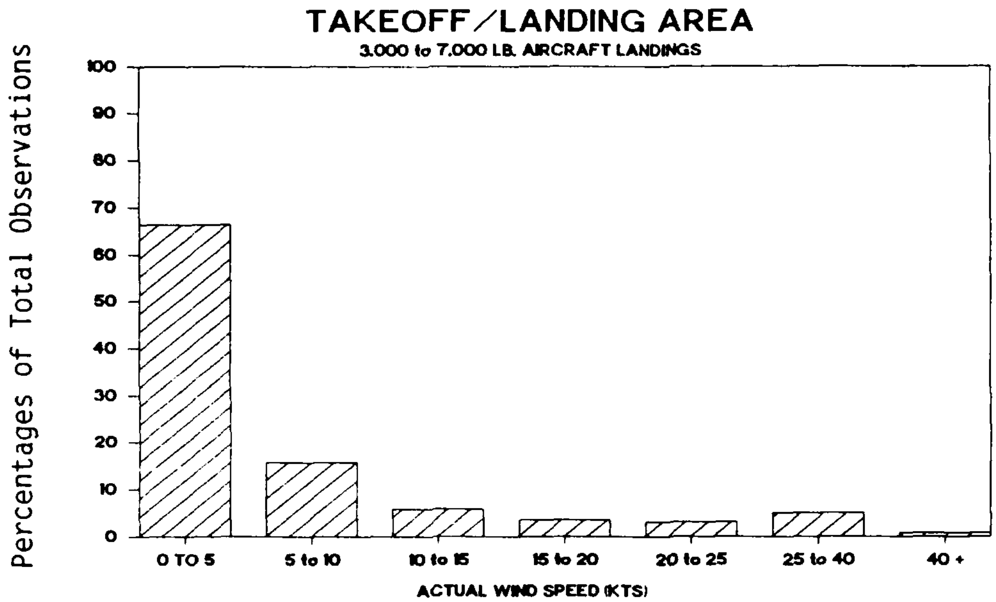
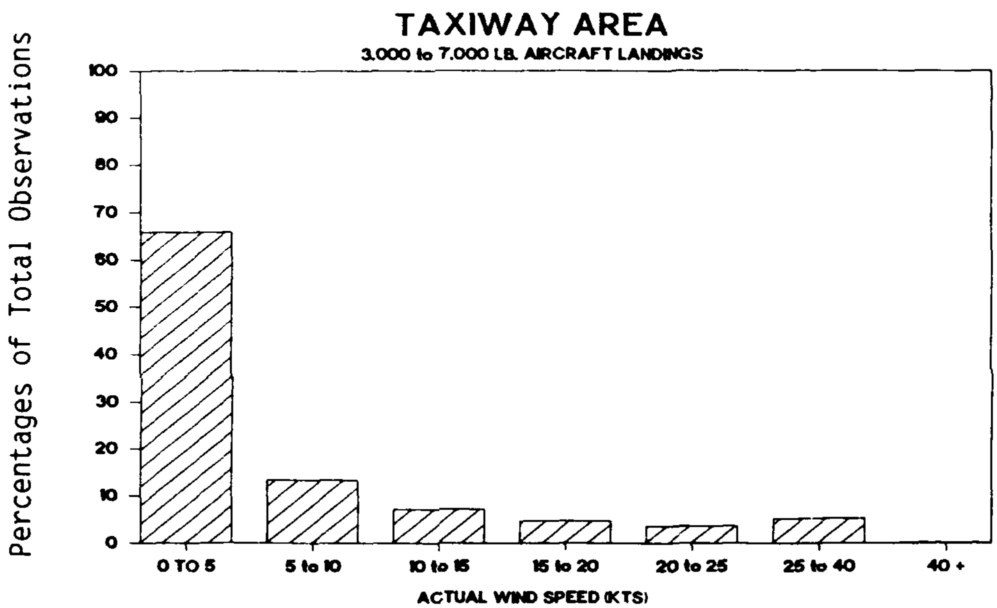


FIGURE 4. SAMPLE WIND DIRECTION PLOTS (SHEET 2 OF 2)





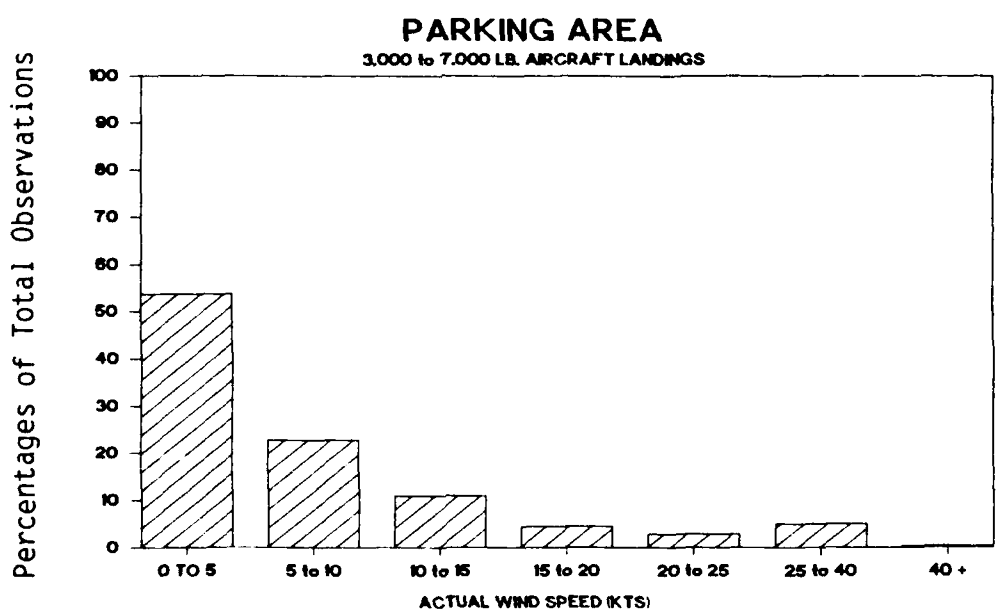


FIGURE 5. HISTOGRAMS OF WIND OBSERVATIONS FOR THE WALL STREET HELIPORT APPROACHES (SHEET 1 OF 2)

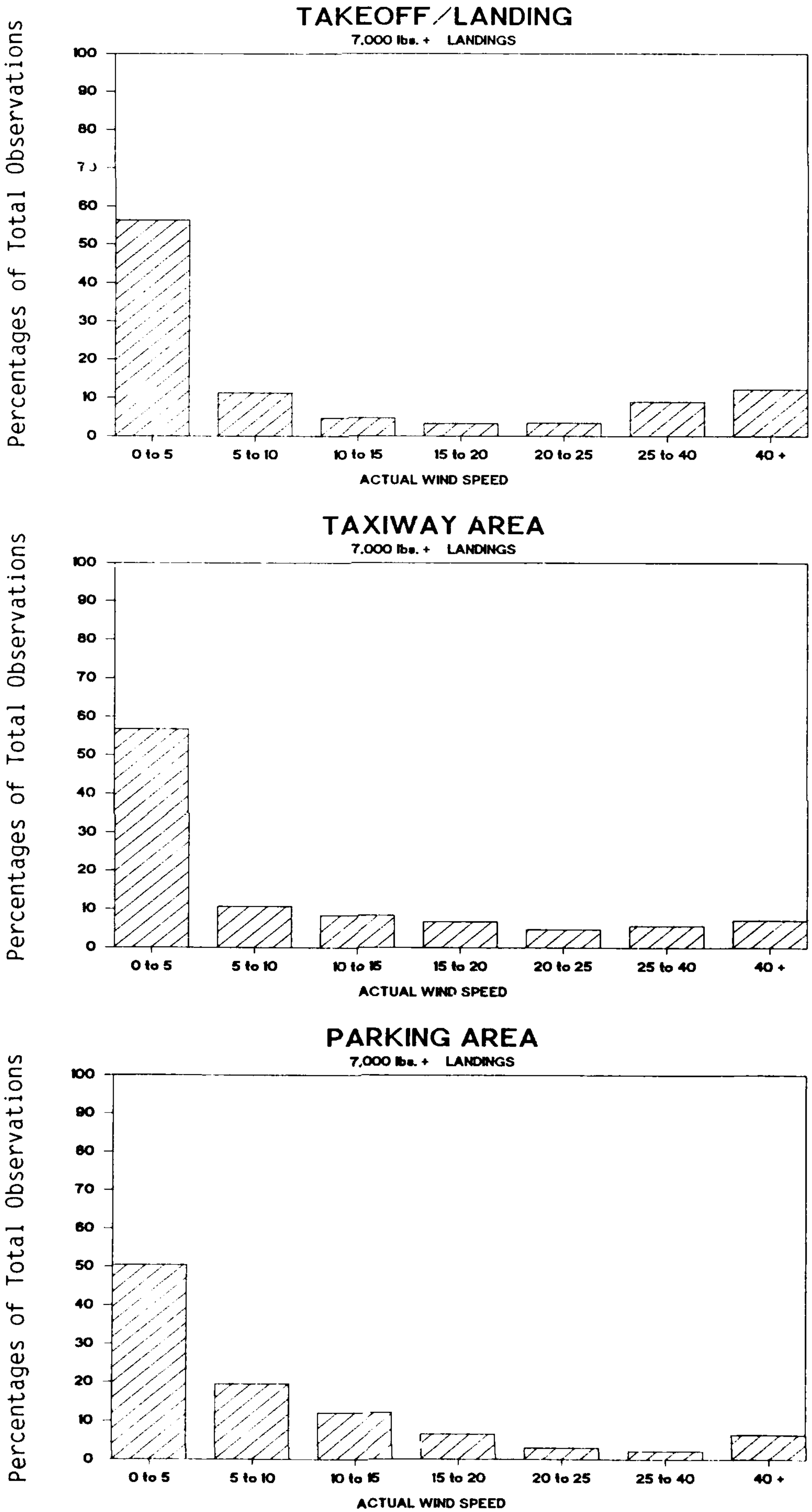


FIGURE 5. HISTOGRAMS OF WIND OBSERVATIONS FOR THE WALL STREET HELIPORT APPROACHES (SHEET 2 OF 2)

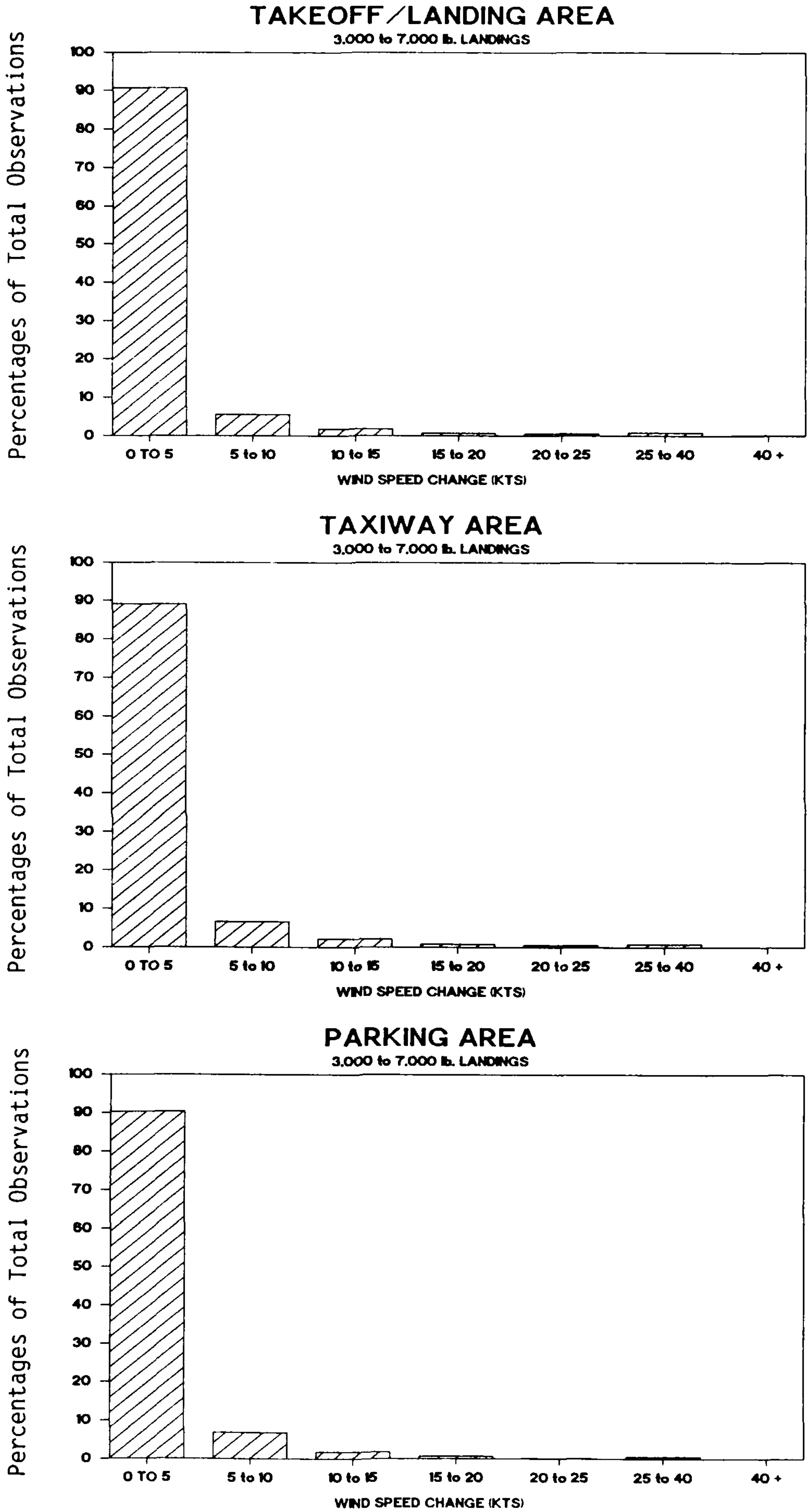
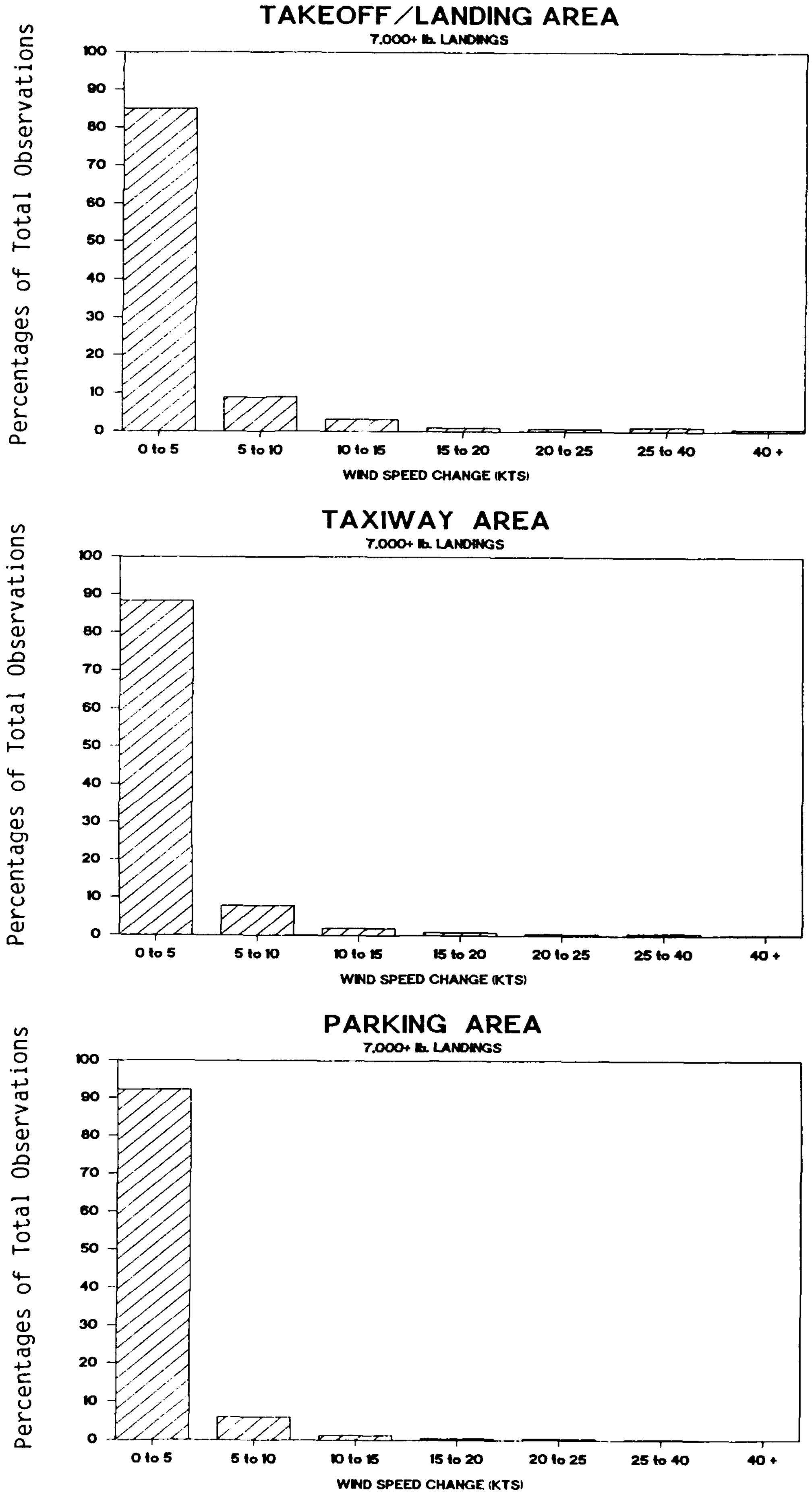


FIGURE 6. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE WALL STREET HELIPORT APPROACHES (SHEET 1 OF 2)



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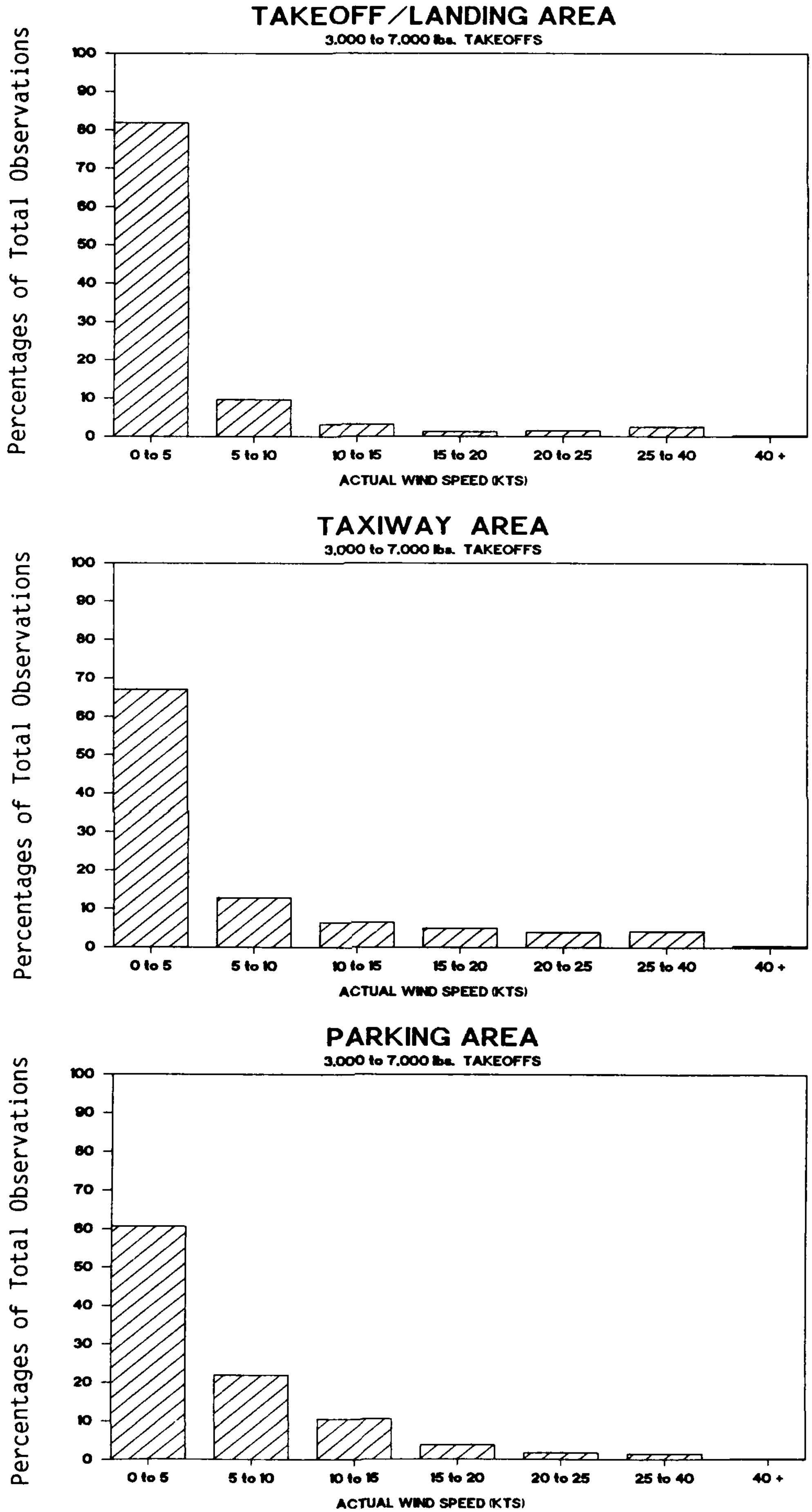
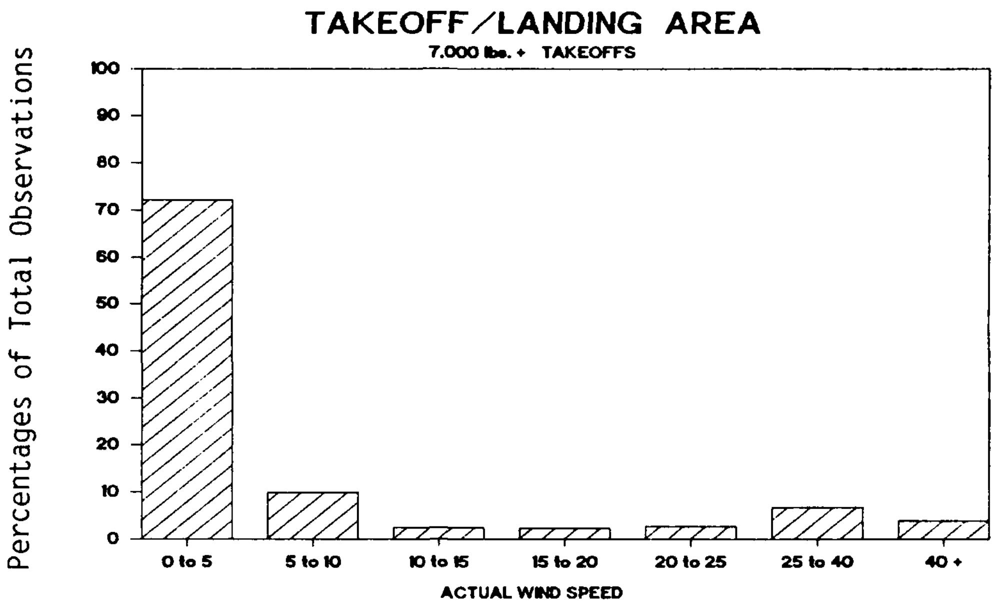
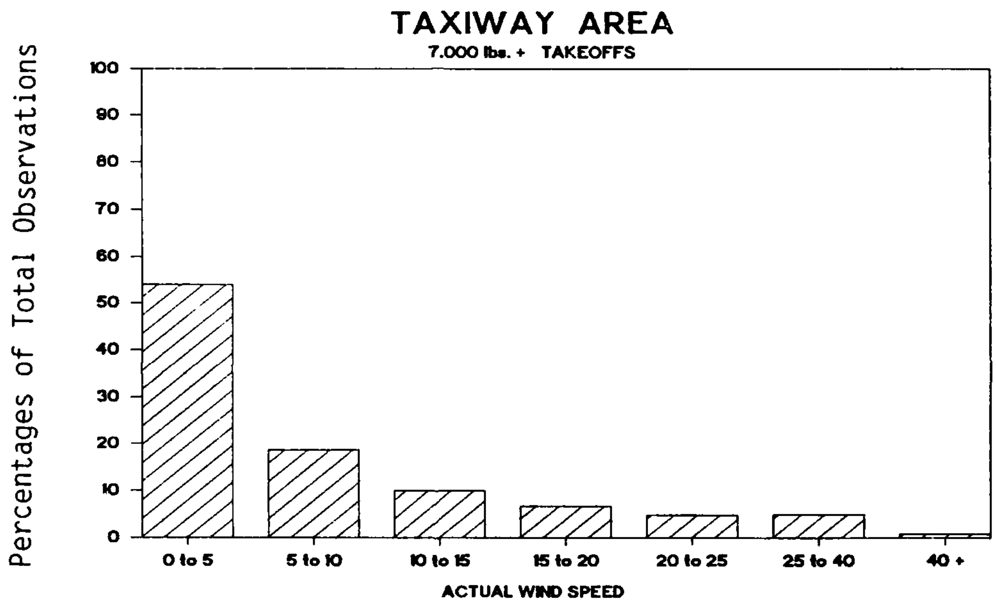
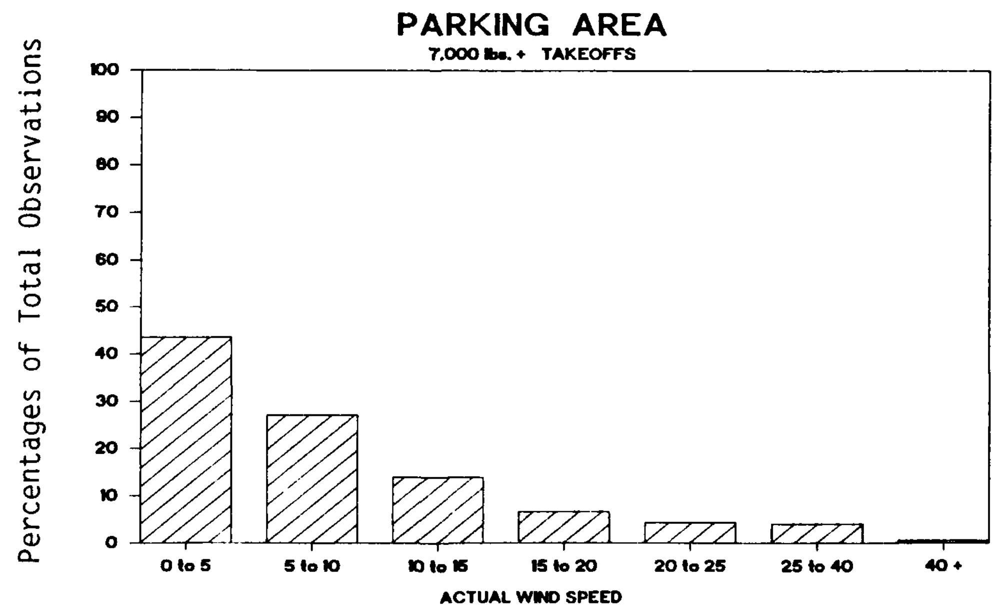


FIGURE 7. HISTOGRAMS OF WIND OBSERVATIONS FOR THE WALL STREET HELIPORT DEPARTURES (SHEET 1 OF 2)







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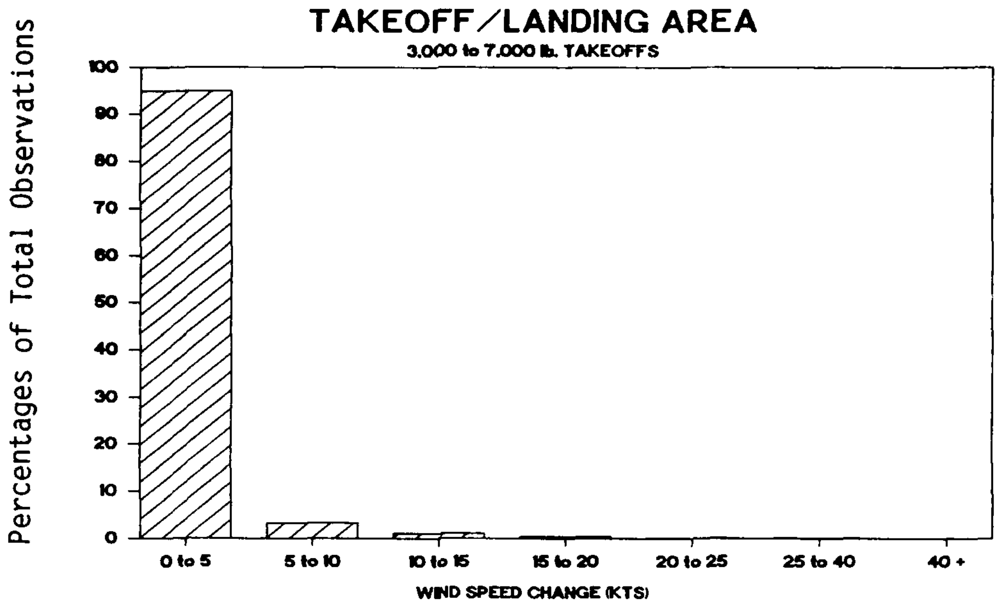
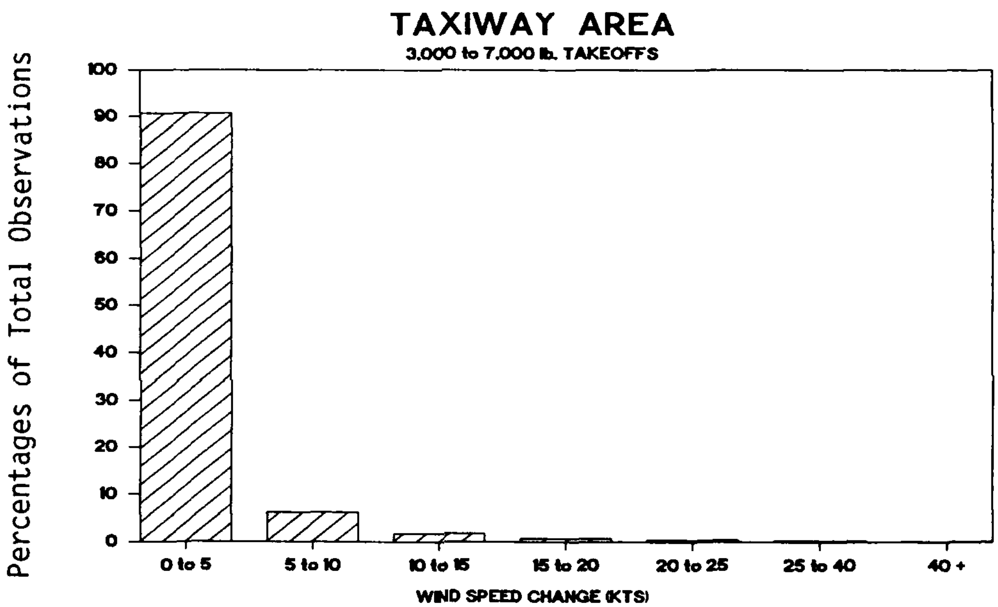




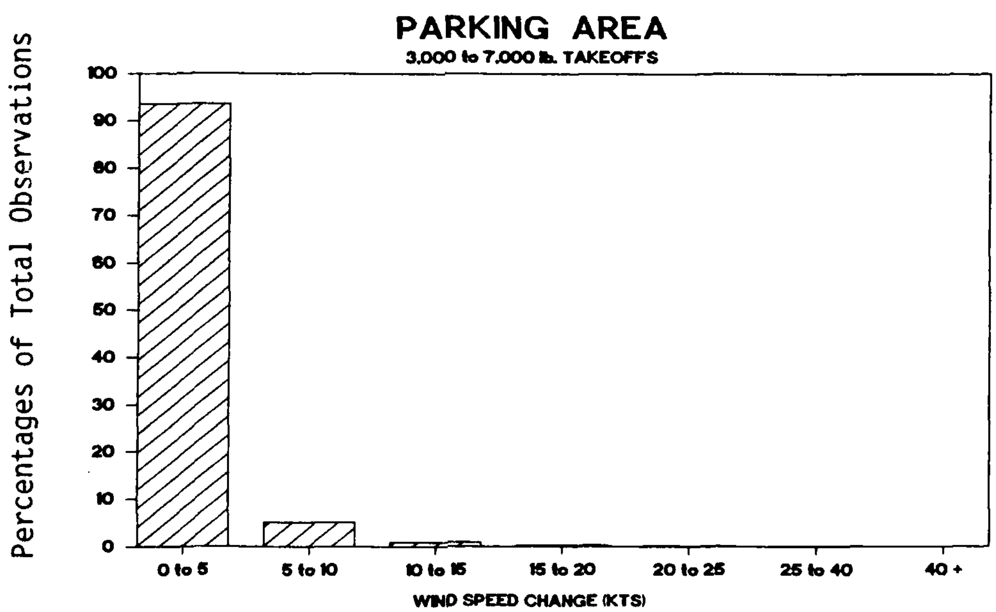
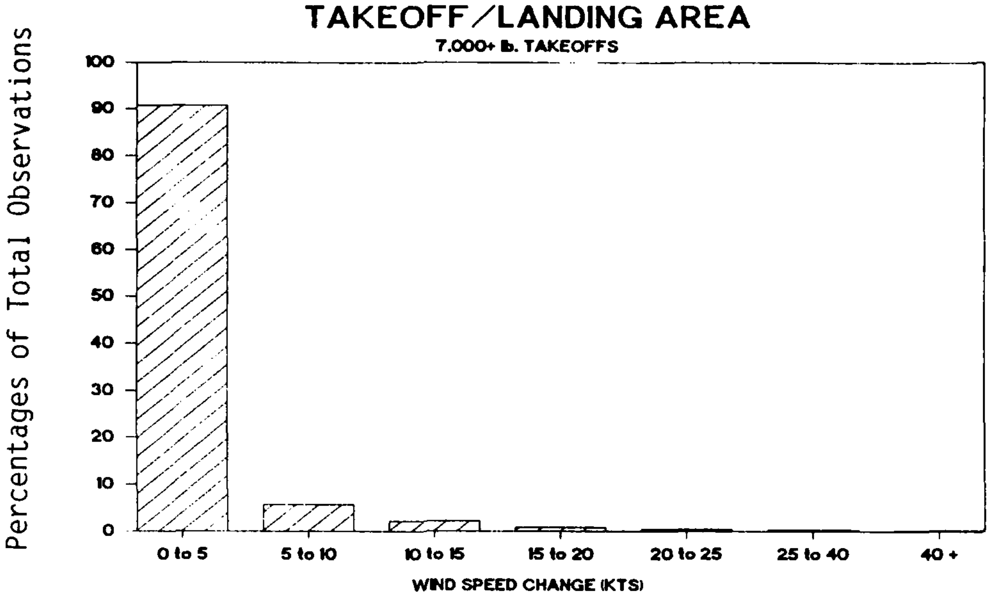
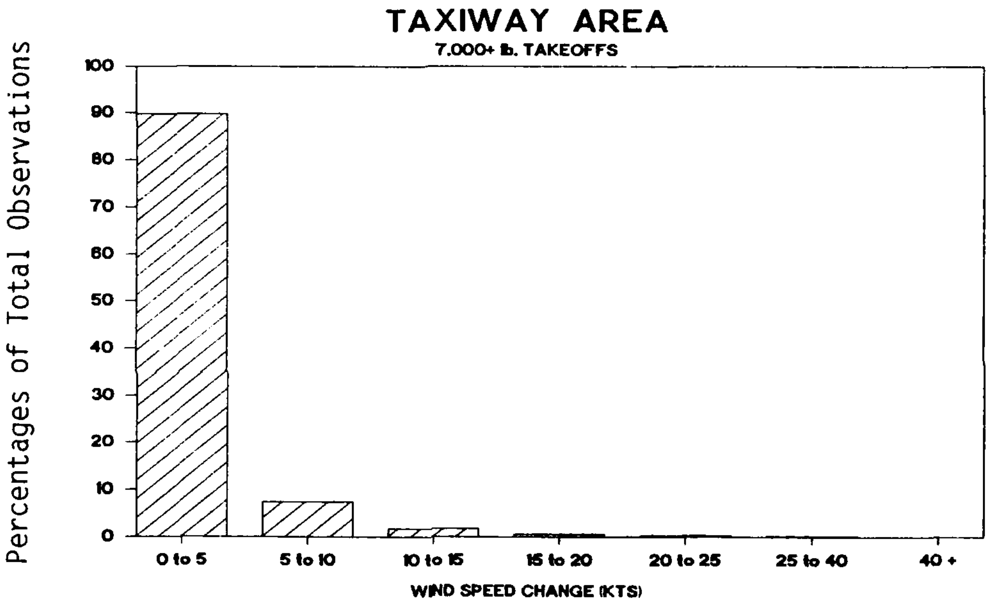


FIGURE 8. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE WALL STREET HELIPORT DEPARTURES (SHEET 1 OF 2)





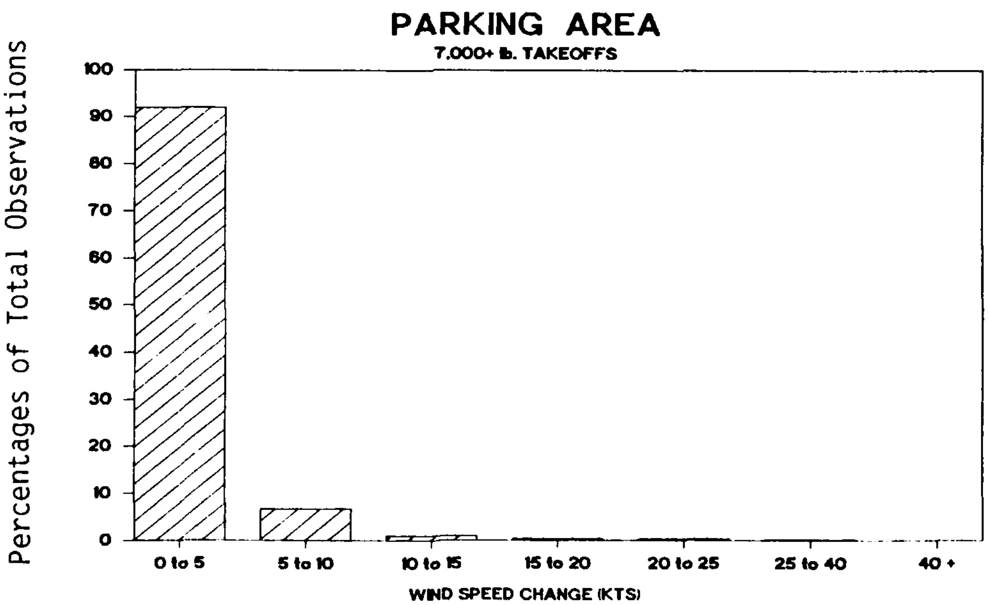


FIGURE 8. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE WALL STREET HELIPORT DEPARTURES (SHEET 2 OF 2)

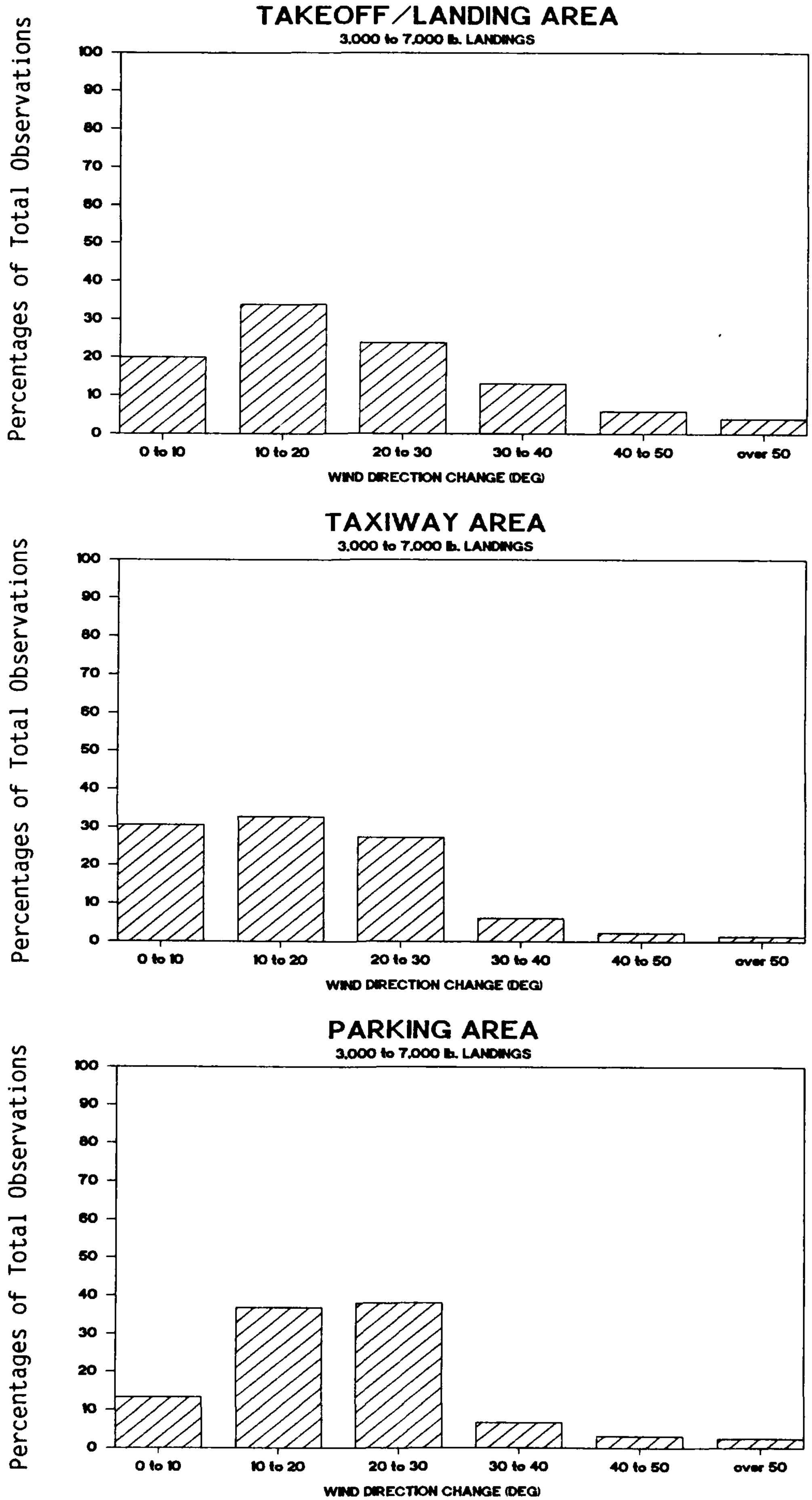
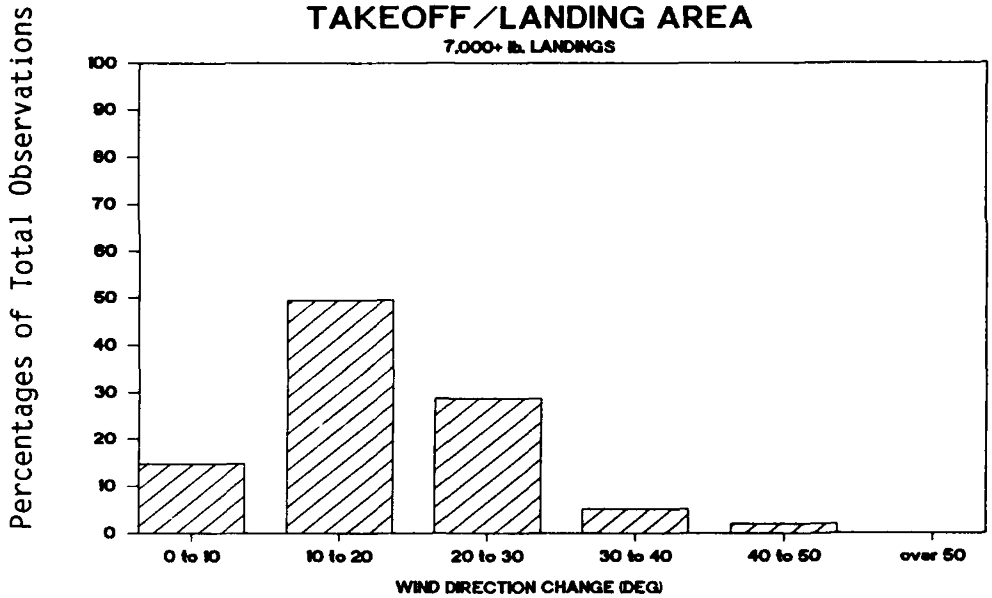
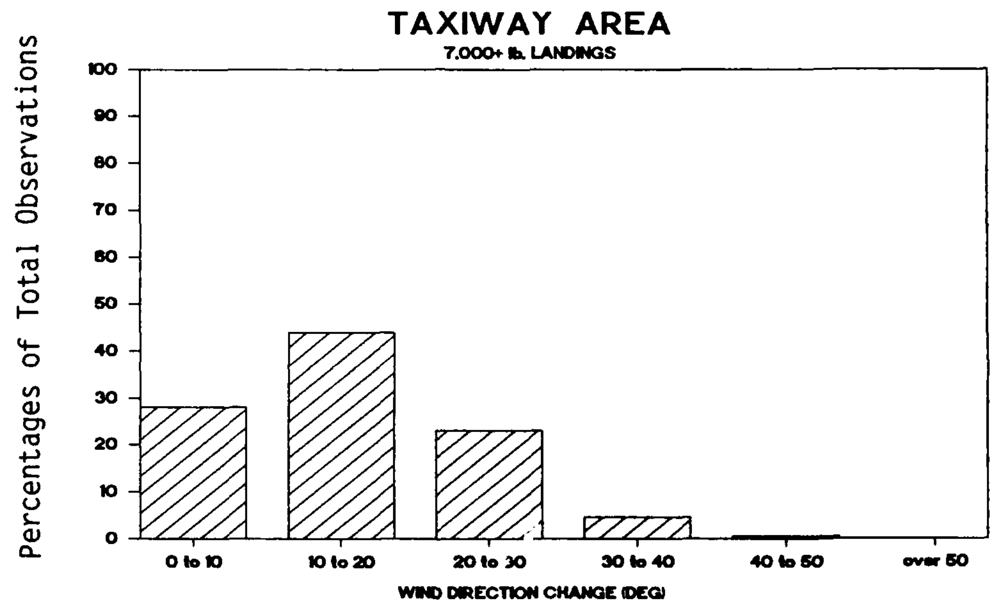


FIGURE 9. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE WALL STREET HELIPORT APPROACHES (SHEET 1 OF 2)





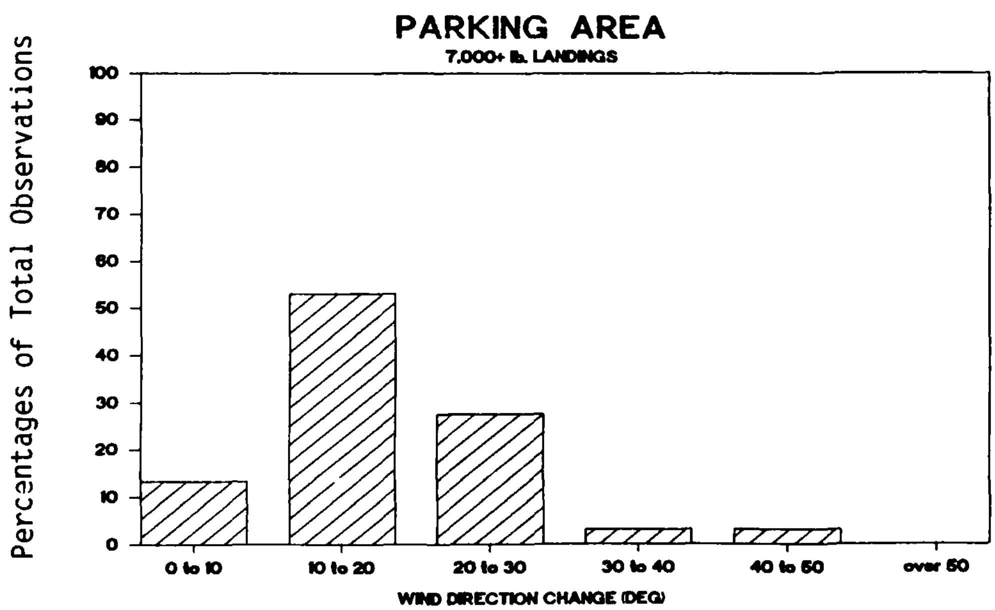


FIGURE 9. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE WALL STREET HELIPORT APPROACHES (SHEET 2 OF 2)

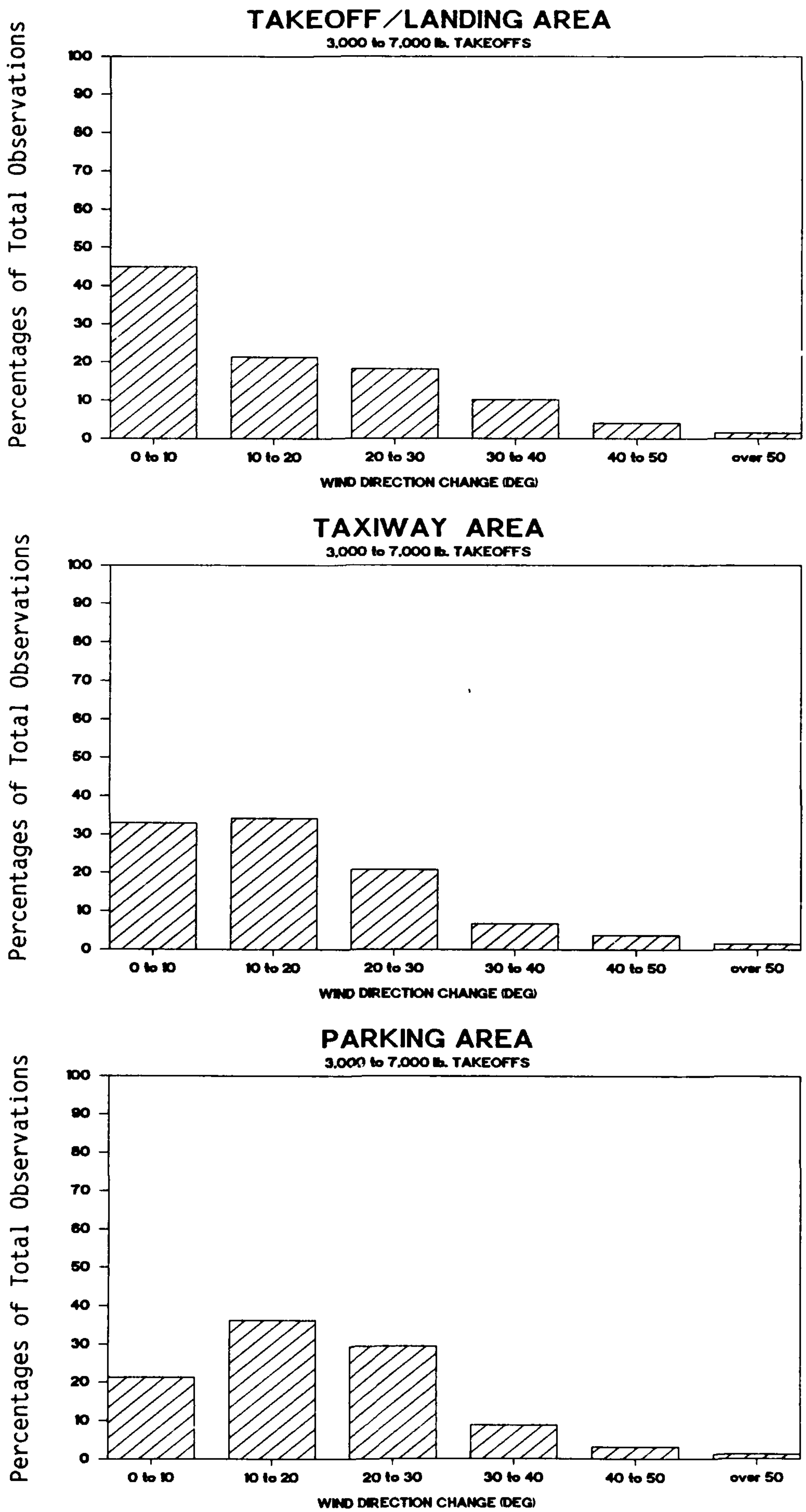
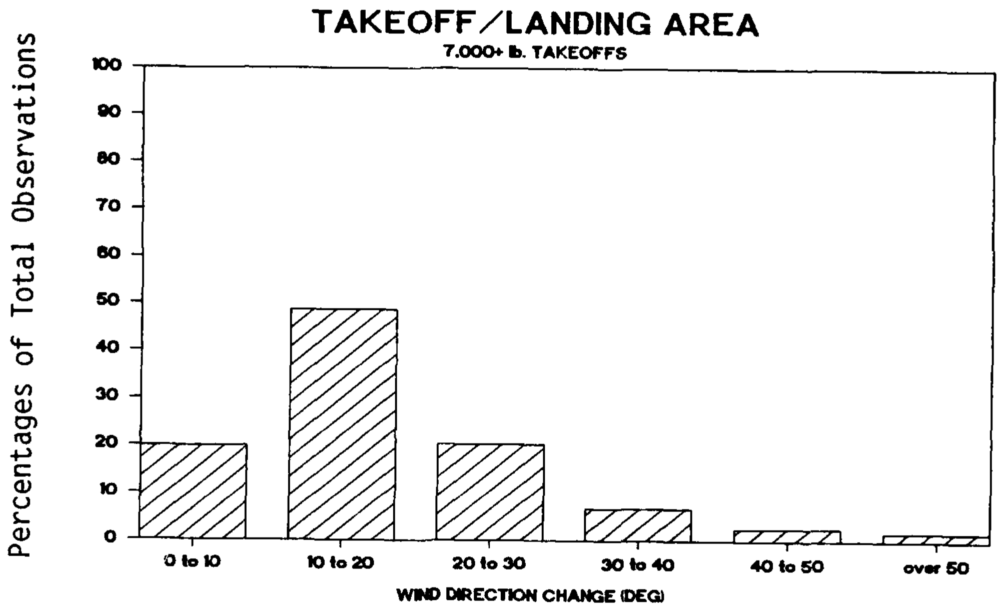
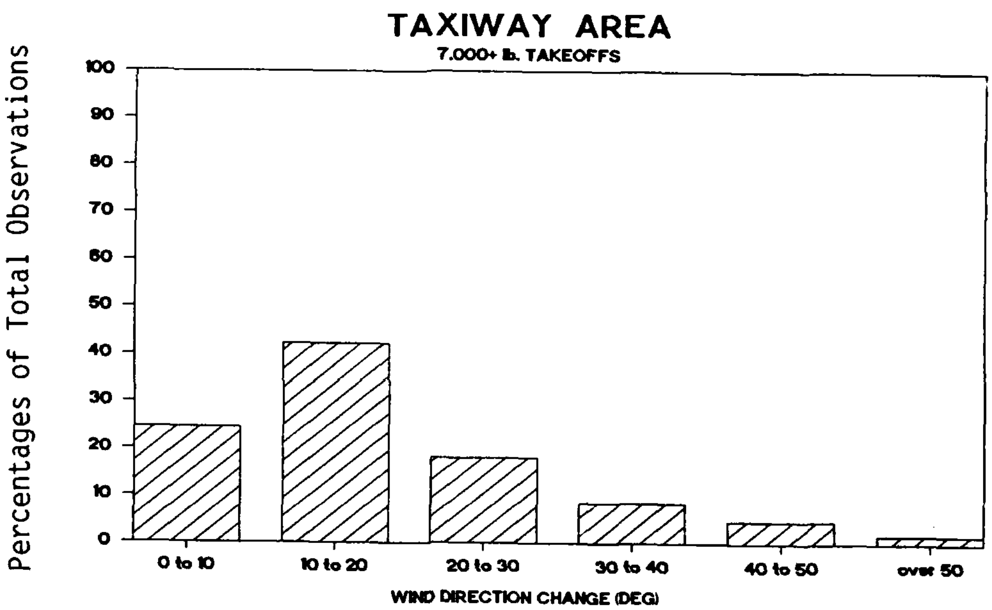


FIGURE 10. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE WALL STREET HELIPORT DEPARTURES (SHEET 1 OF 2)





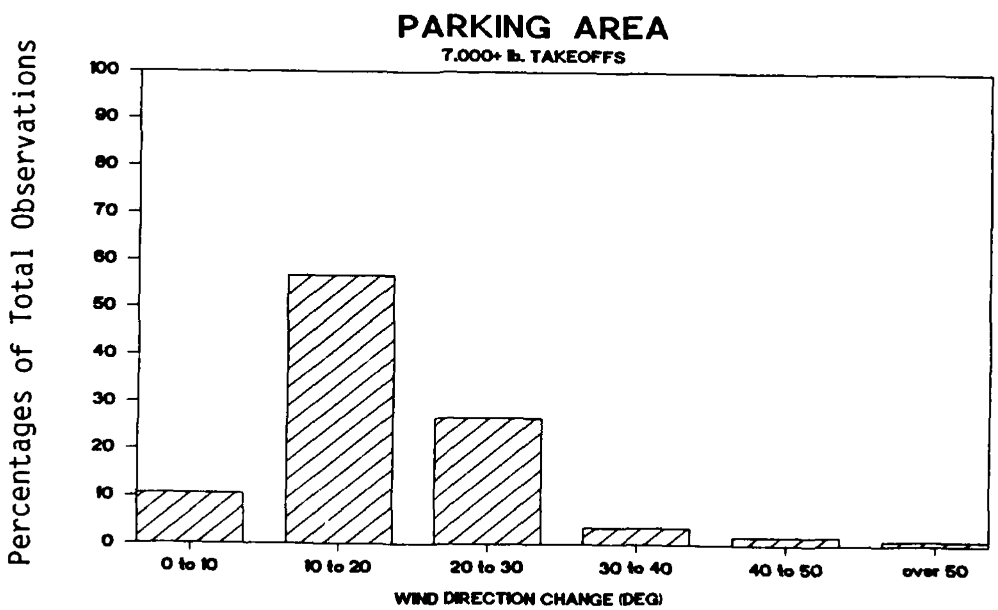


FIGURE 10. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE WALL STREET HELIPORT DEPARTURES (SHEET 2 OF 2)

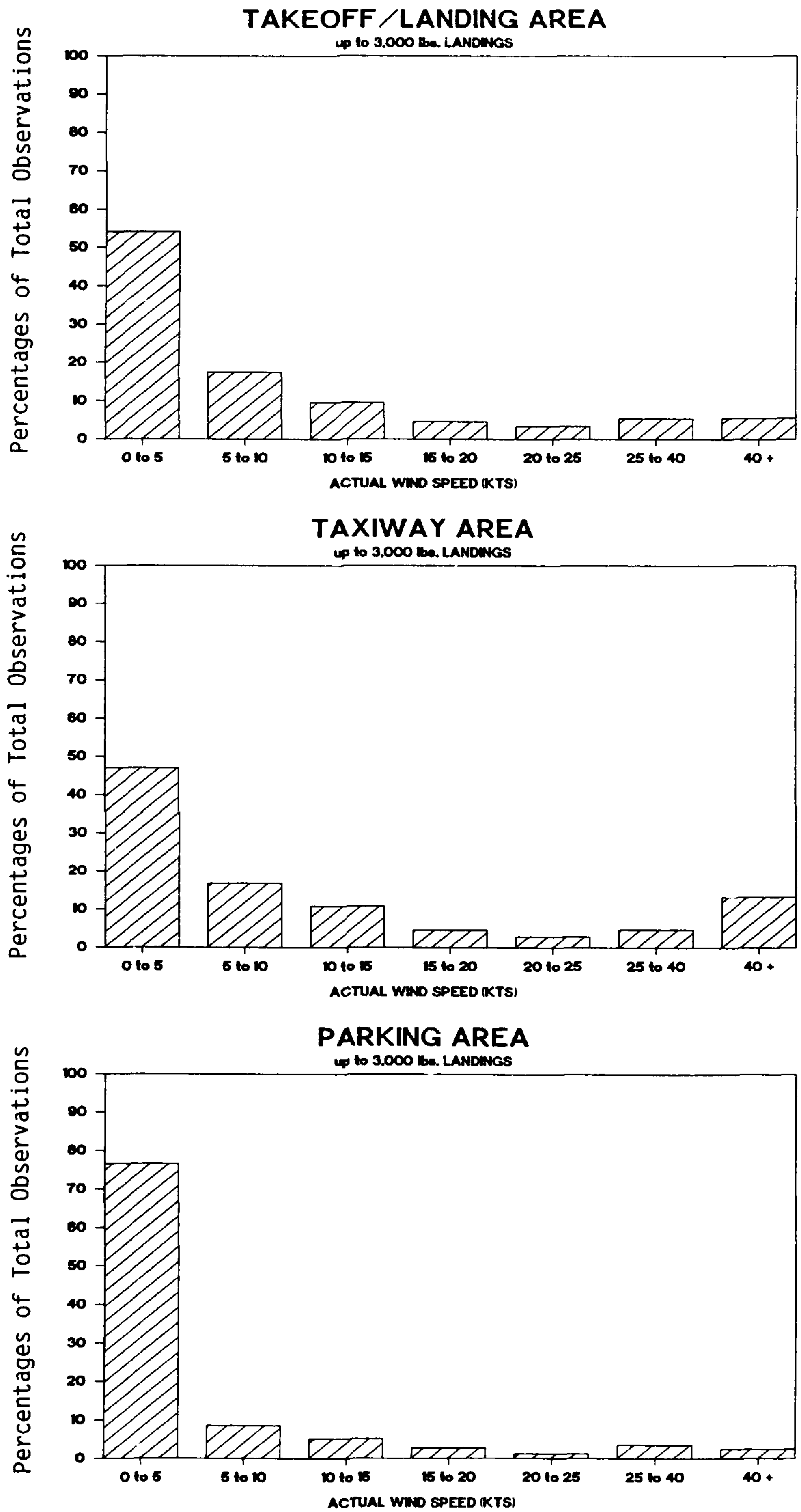


FIGURE 11. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 1 OF 3)

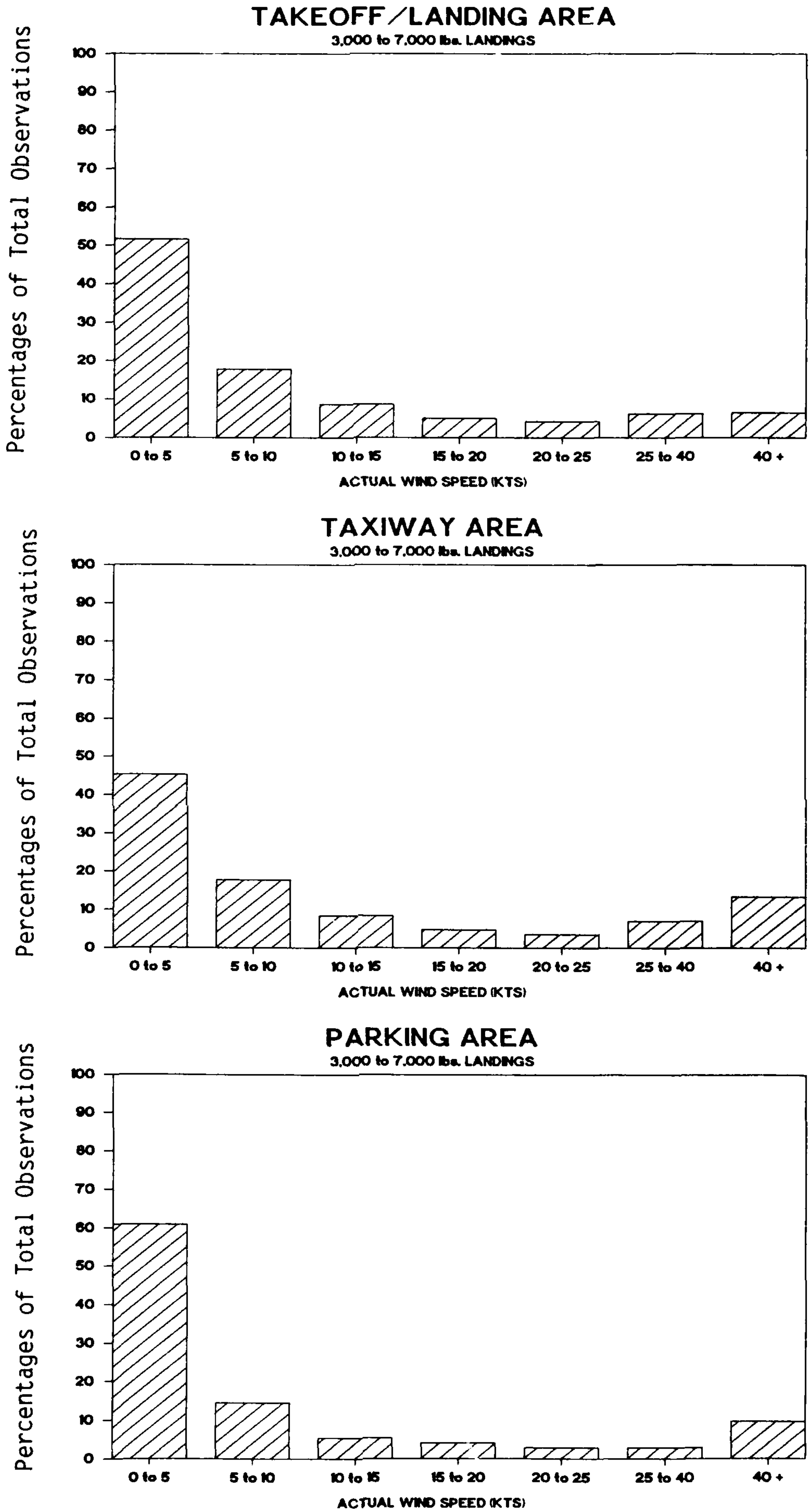
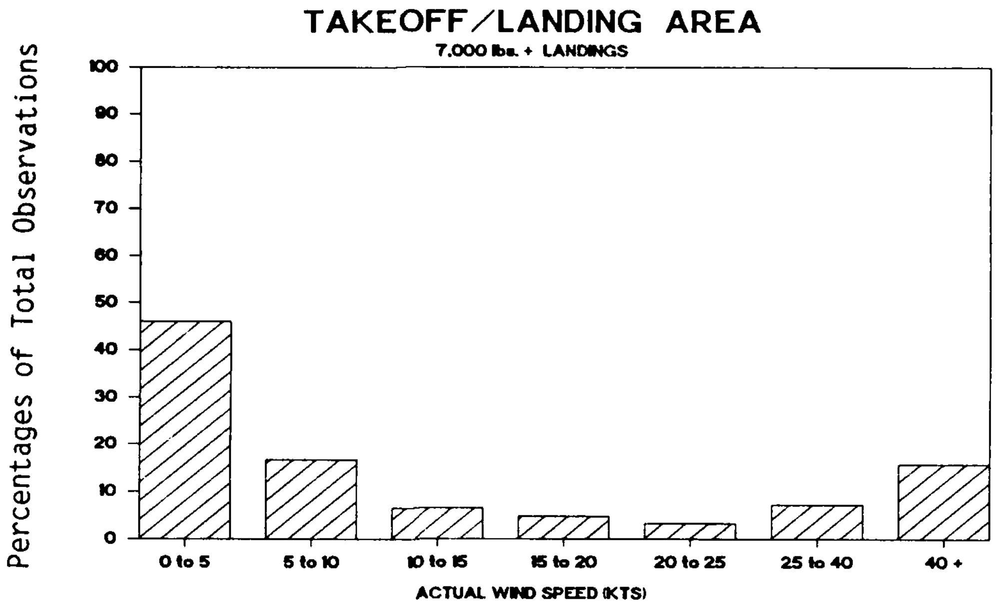
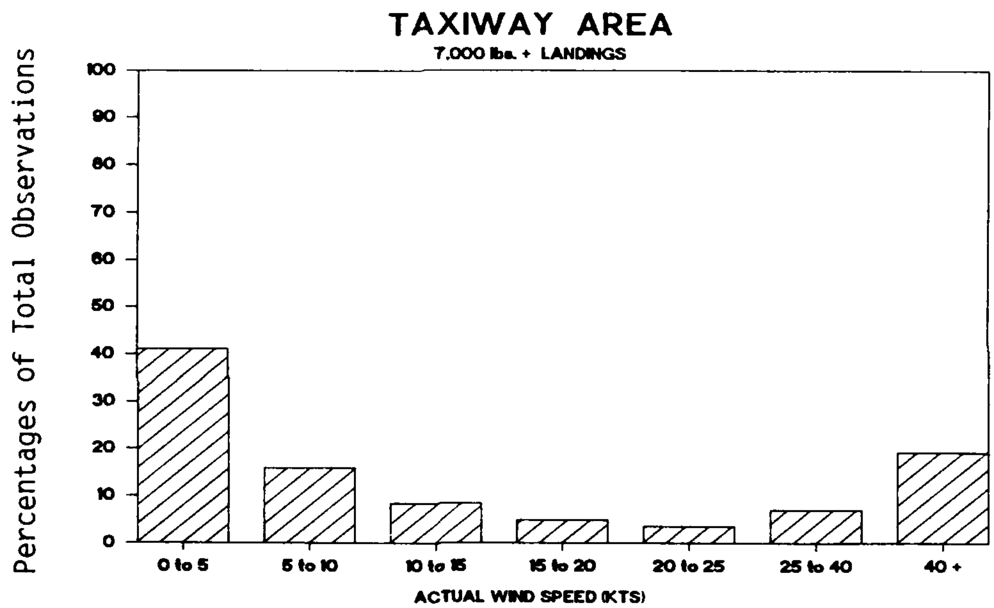


FIGURE 11. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 2 OF 3)





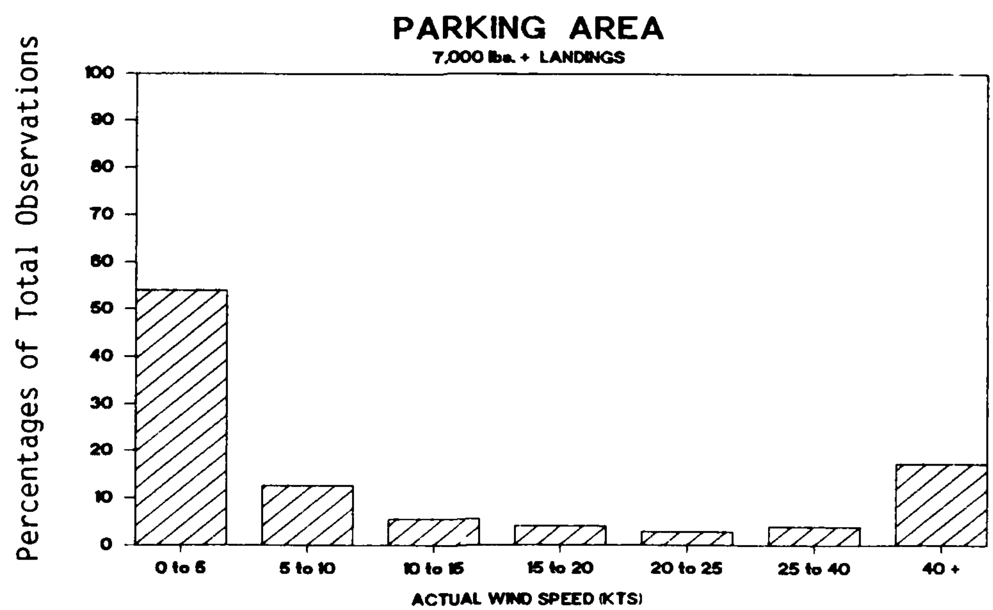


FIGURE 11. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 3 OF 3)

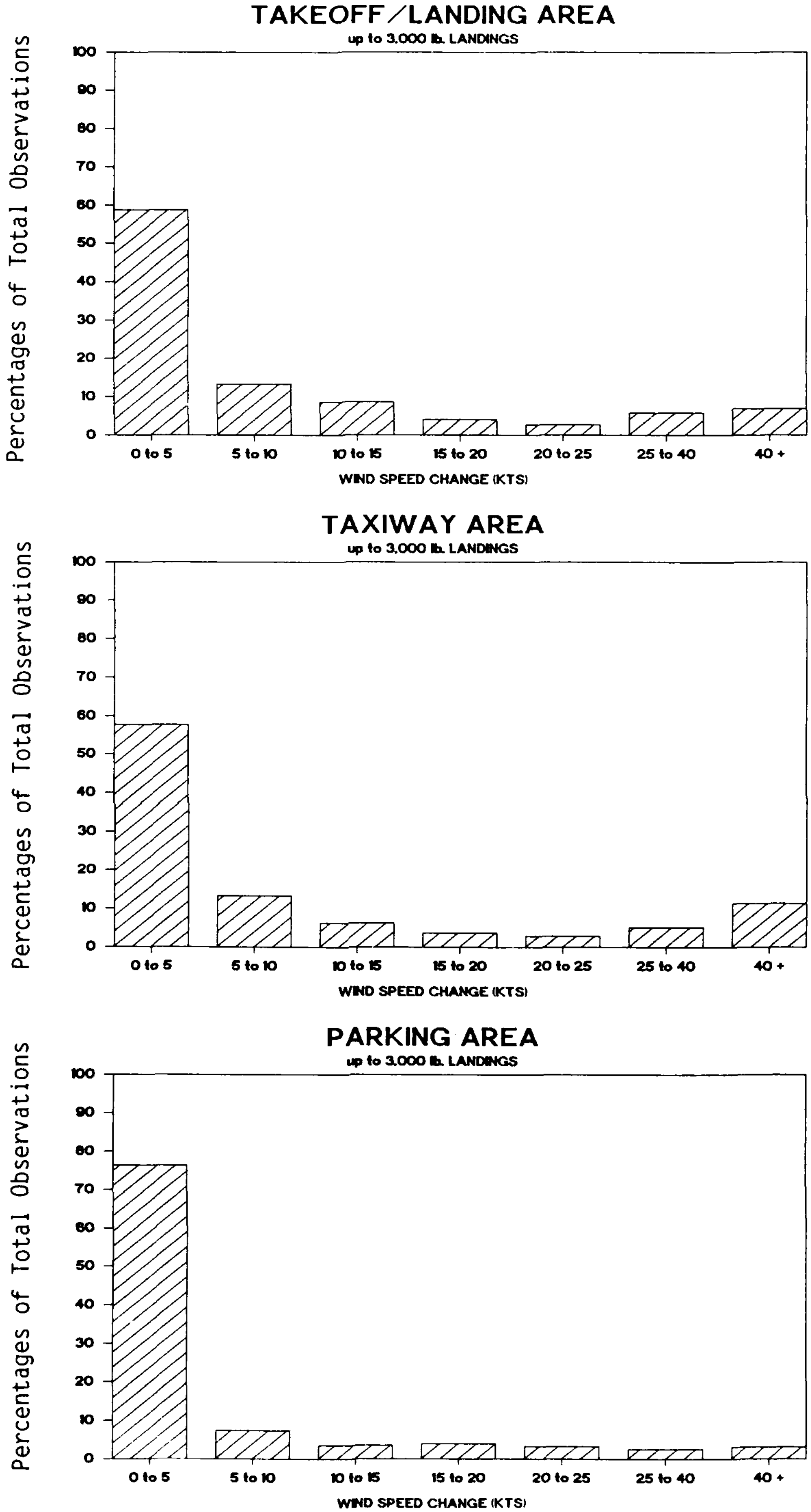


FIGURE 12. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 1 OF 3)

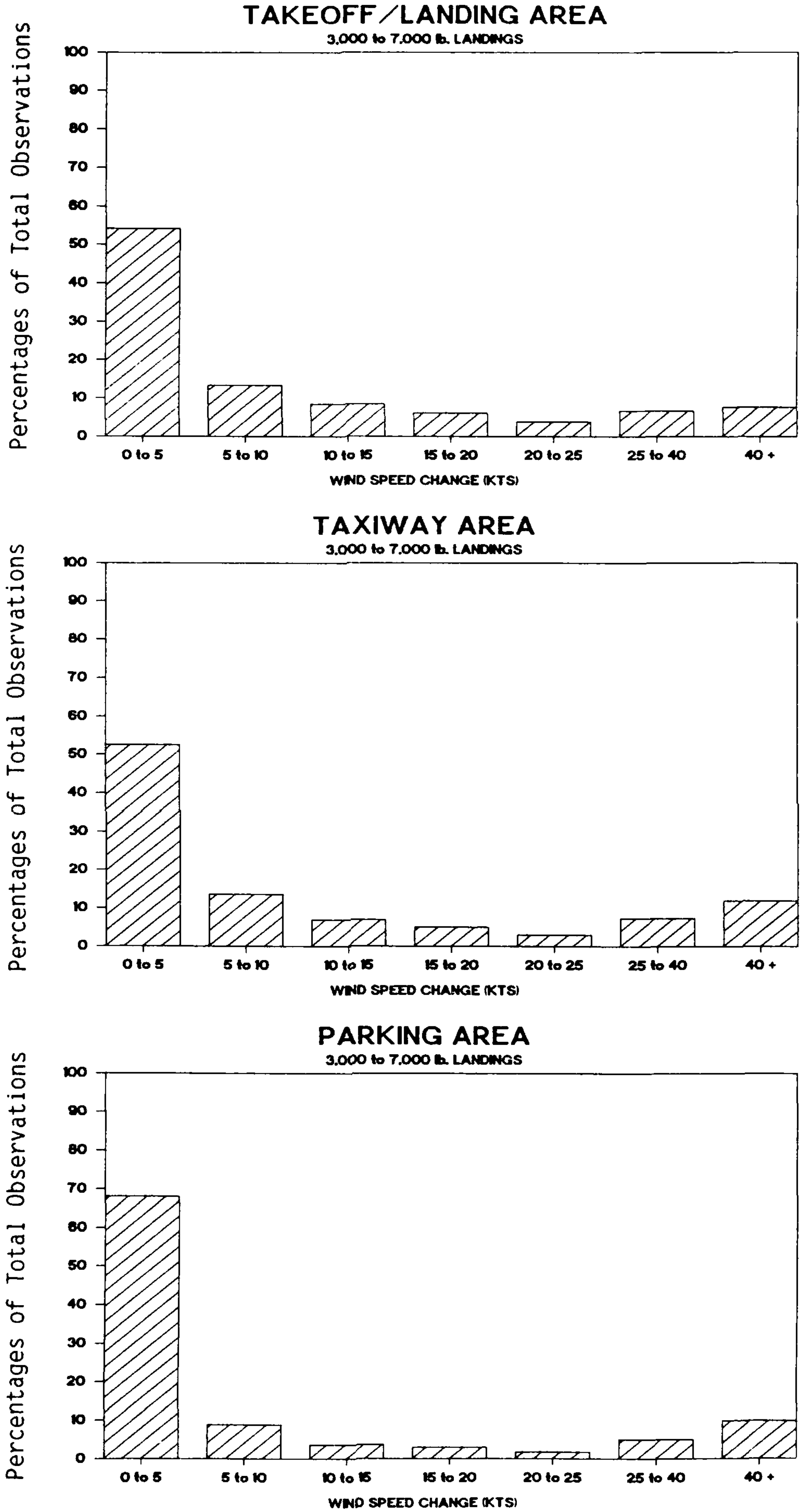
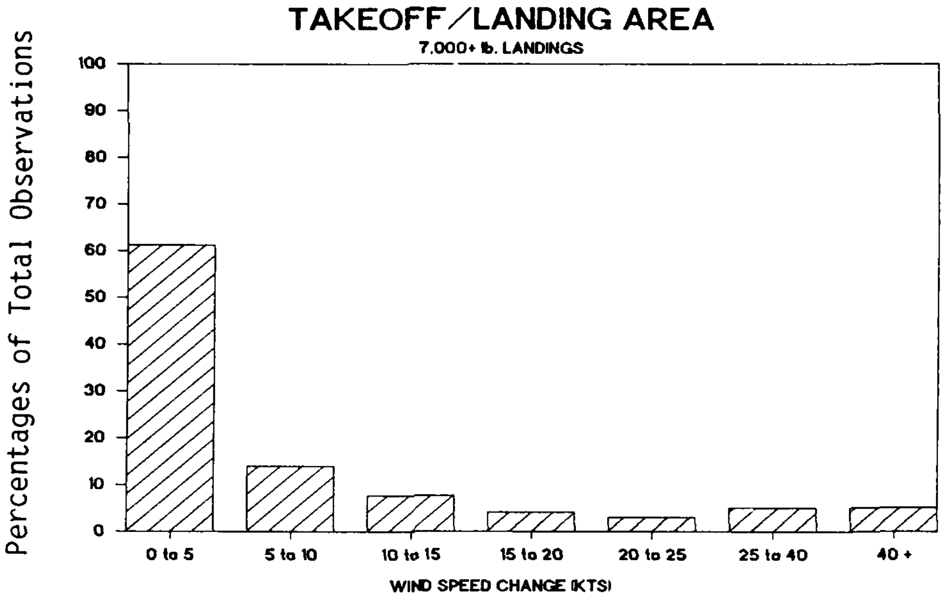
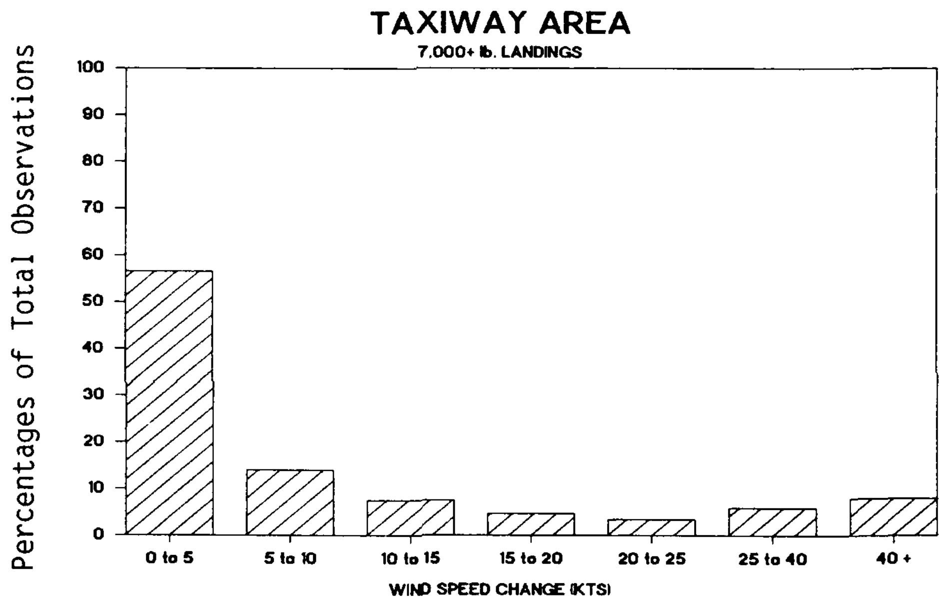


FIGURE 12. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 2 OF 3)





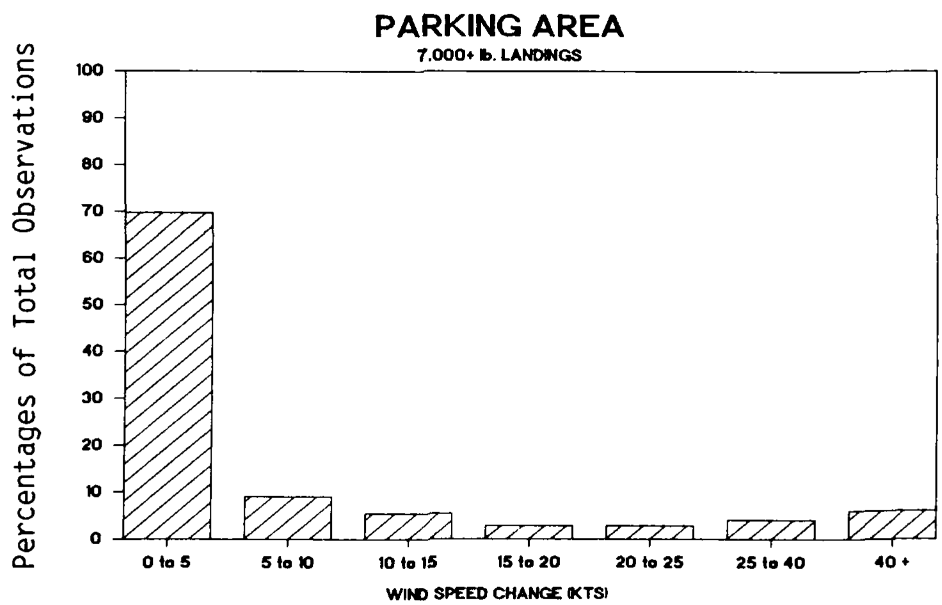
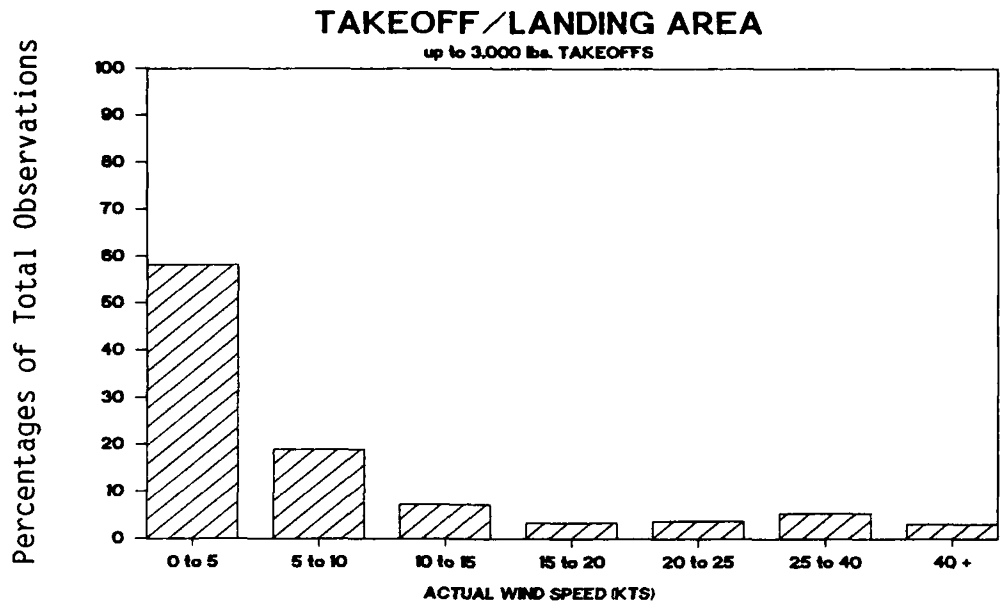
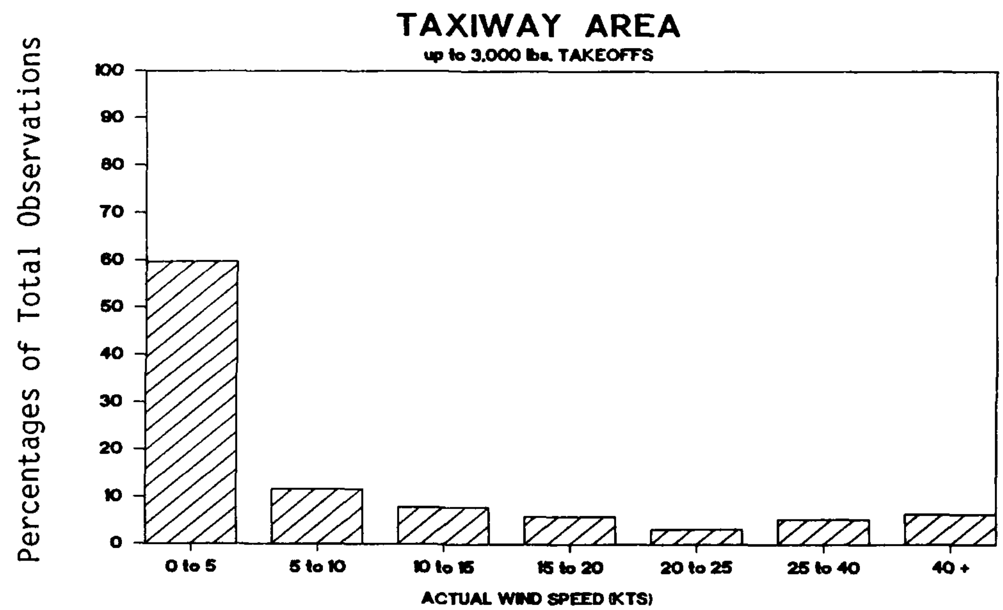


FIGURE 12. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 3 OF 3)





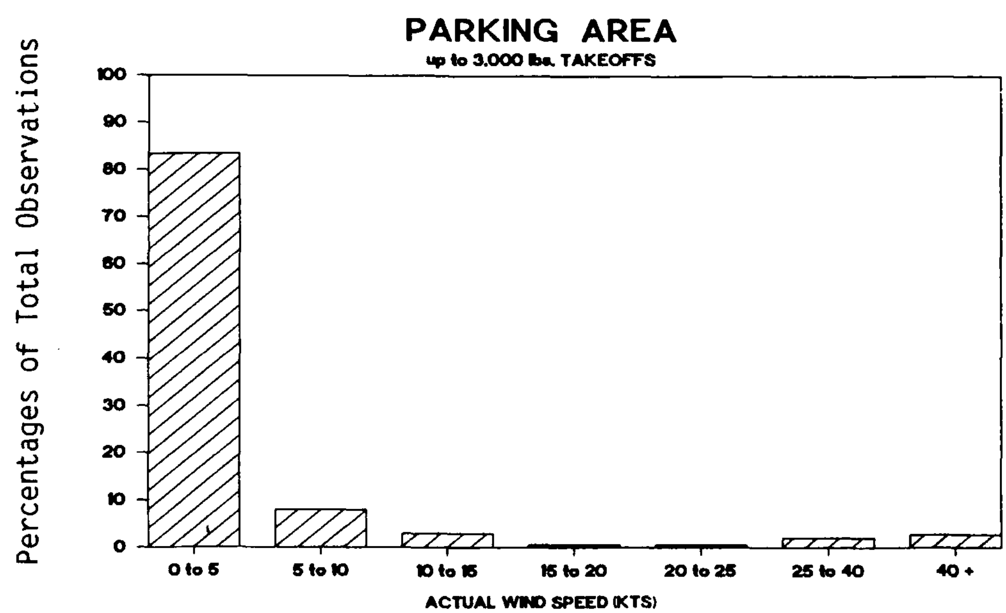


FIGURE 13. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 1 OF 3)

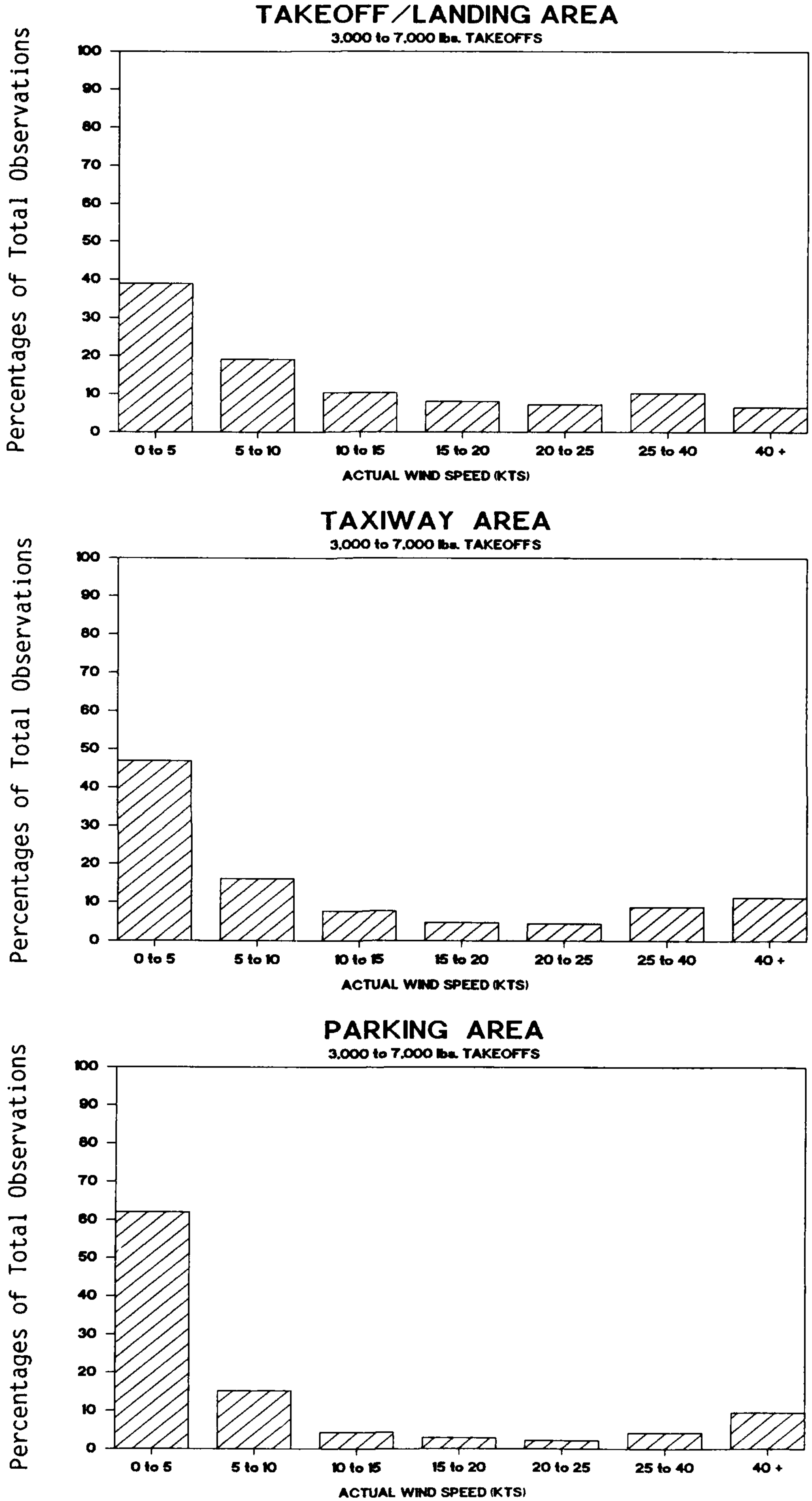
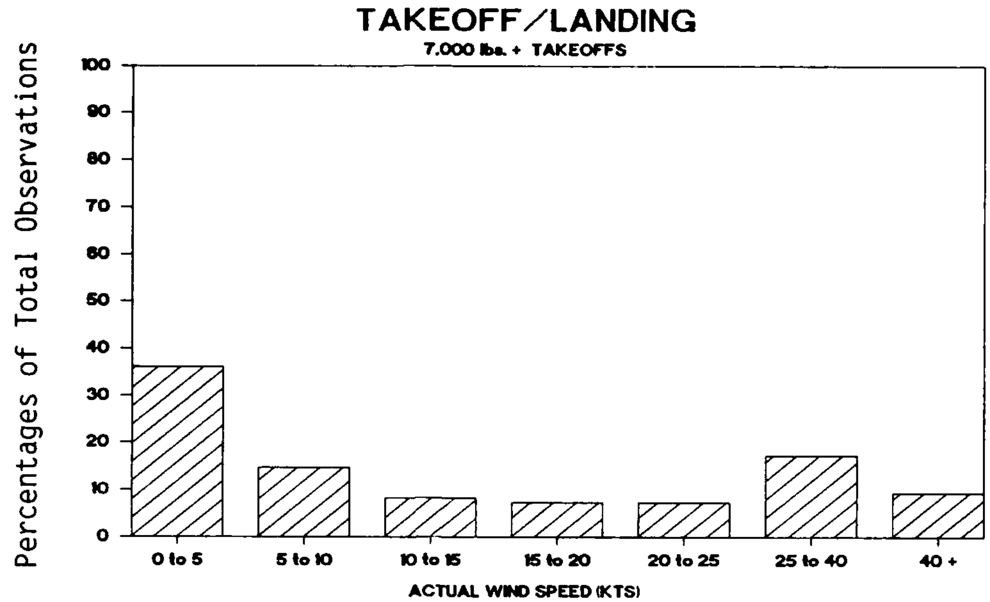
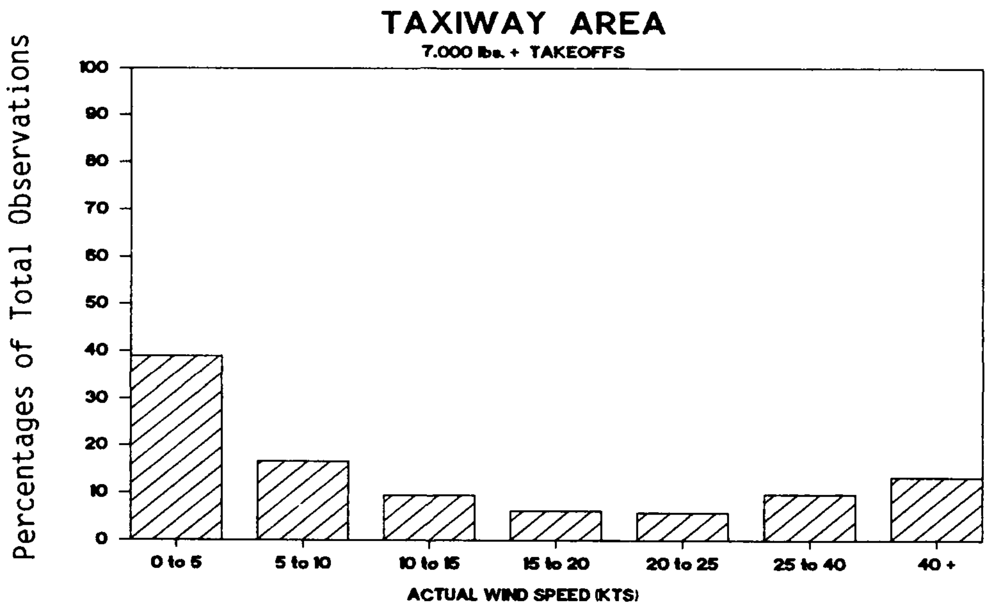


FIGURE 13. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 2 OF 3)





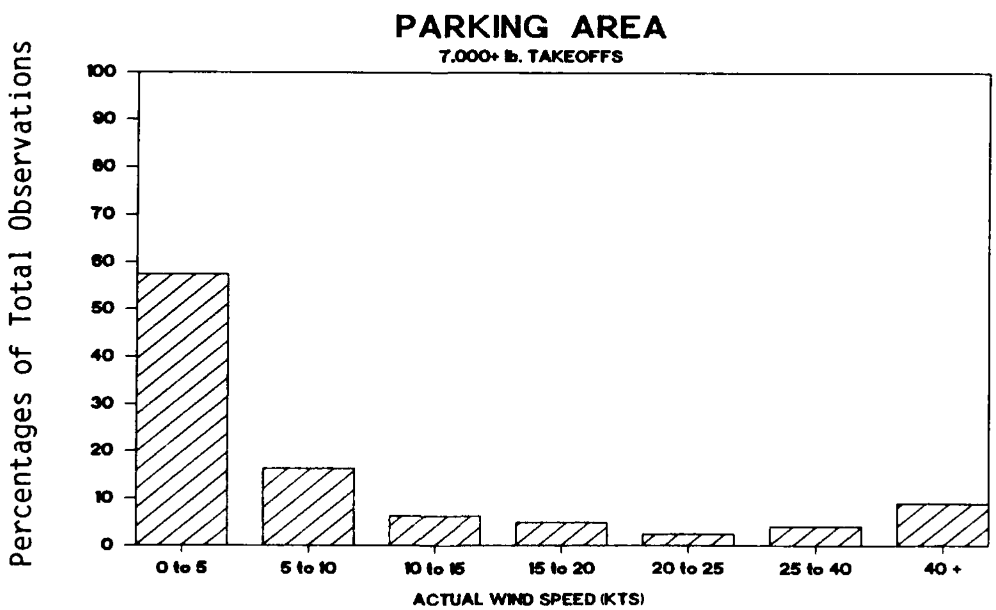
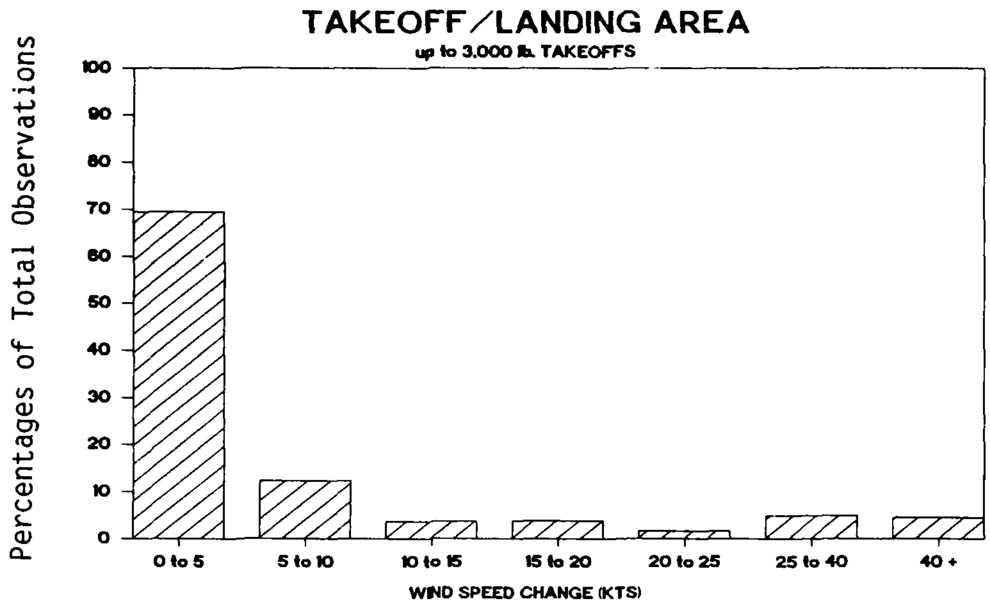
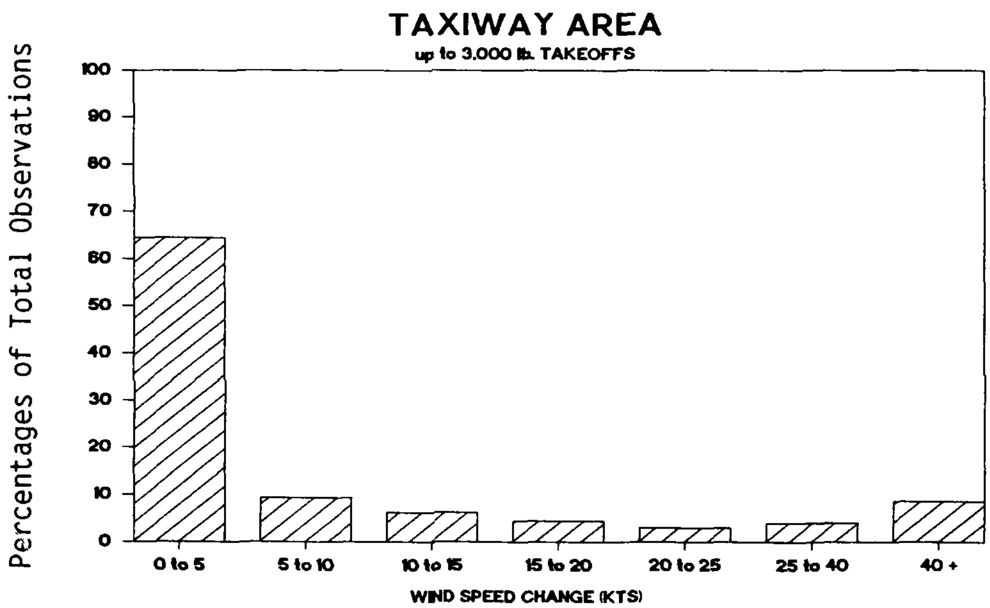


FIGURE 13. HISTOGRAMS OF WIND OBSERVATIONS FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 3 OF 3)





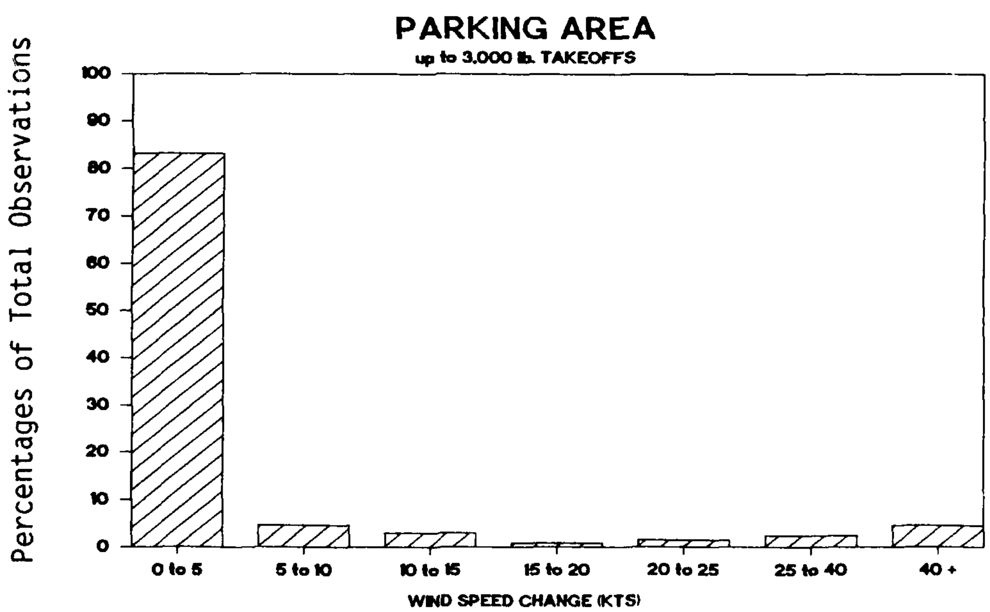
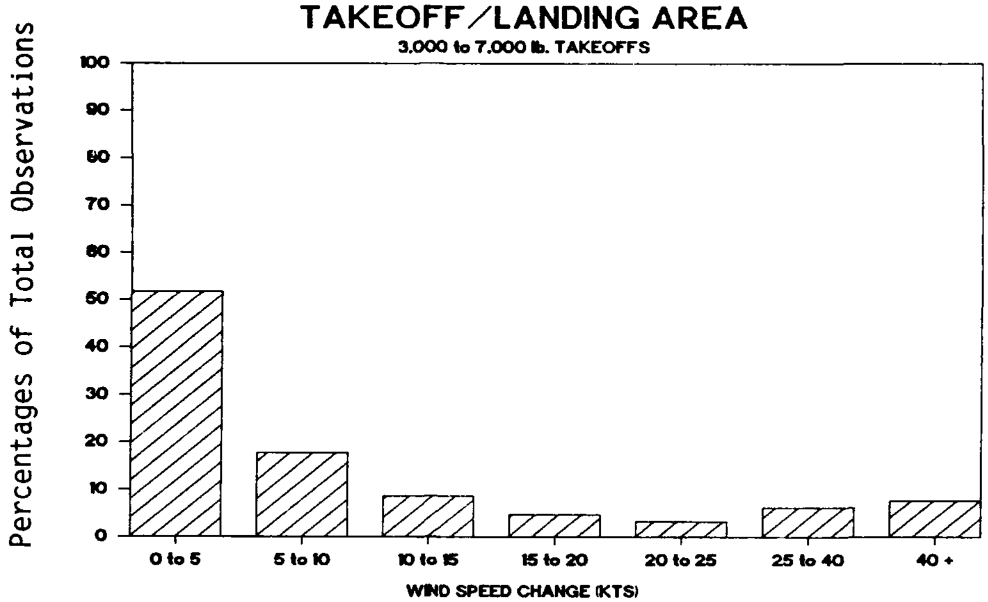
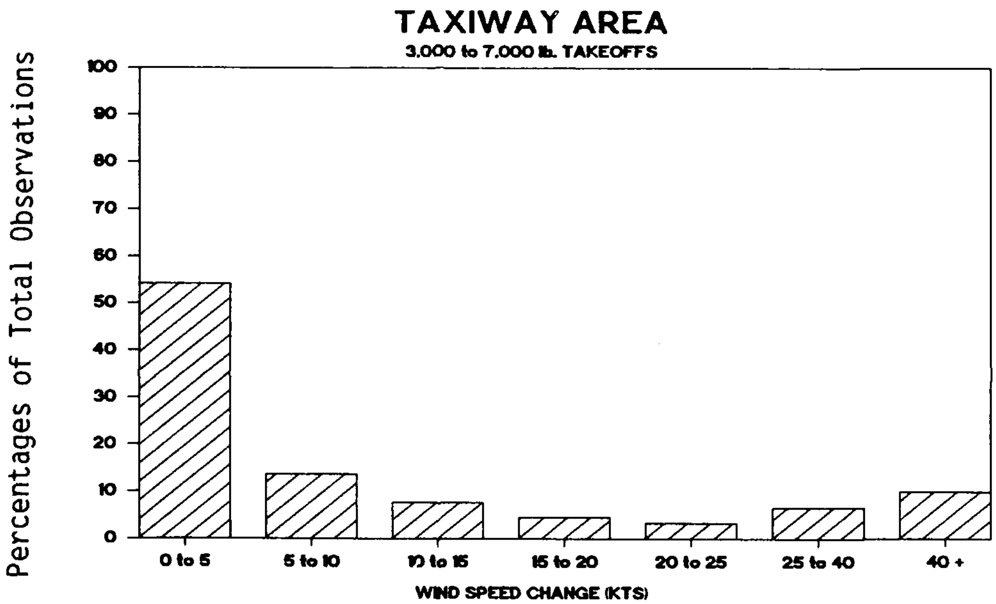


FIGURE 14. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 1 OF 3)





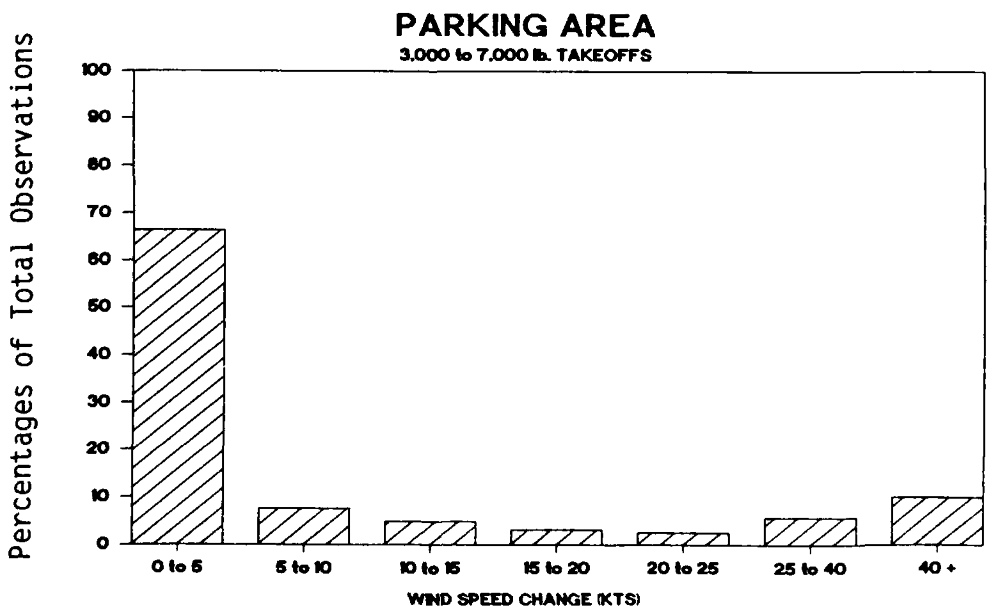
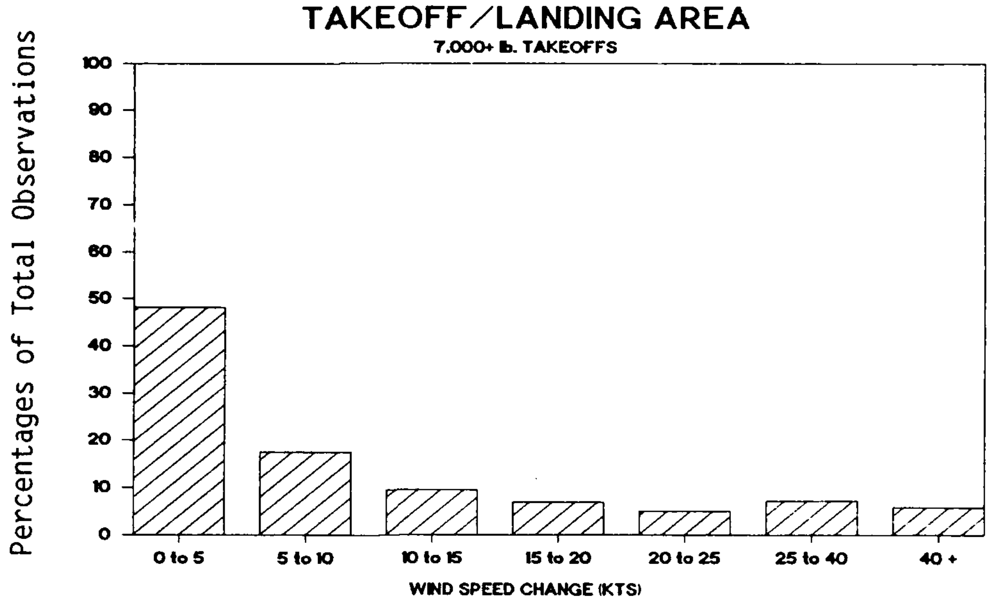
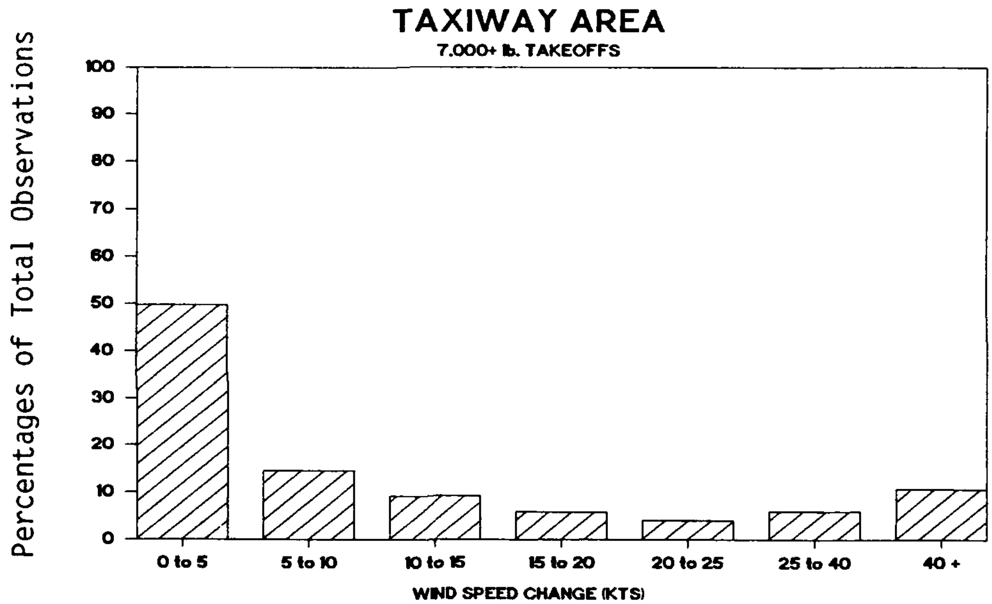


FIGURE 14. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 2 OF 3)





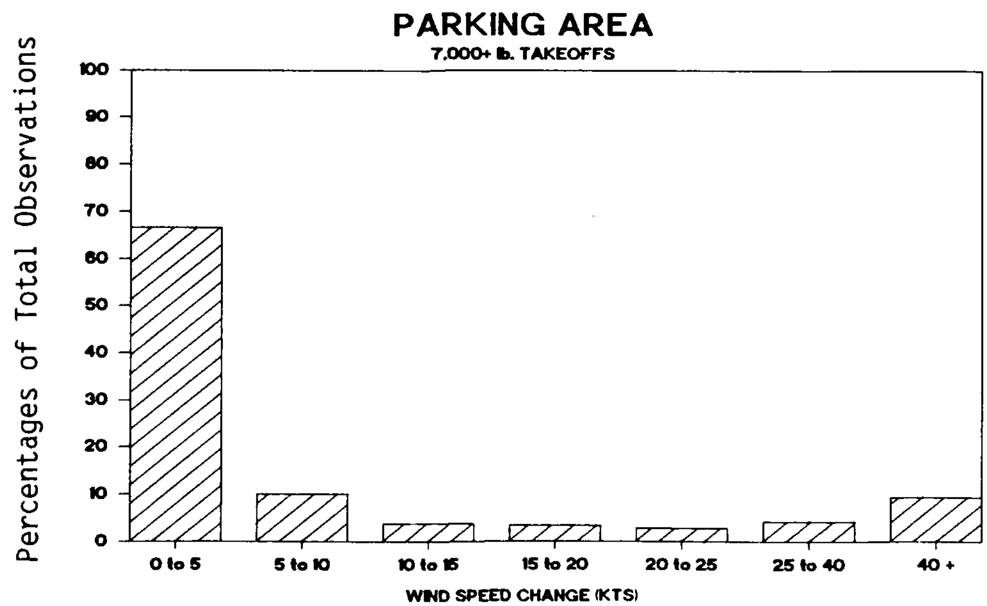
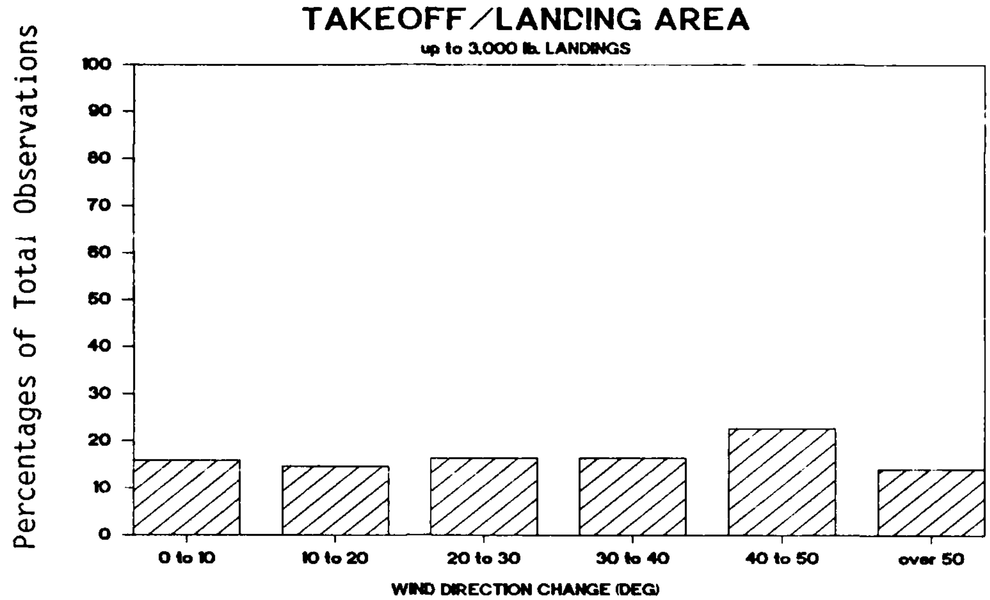
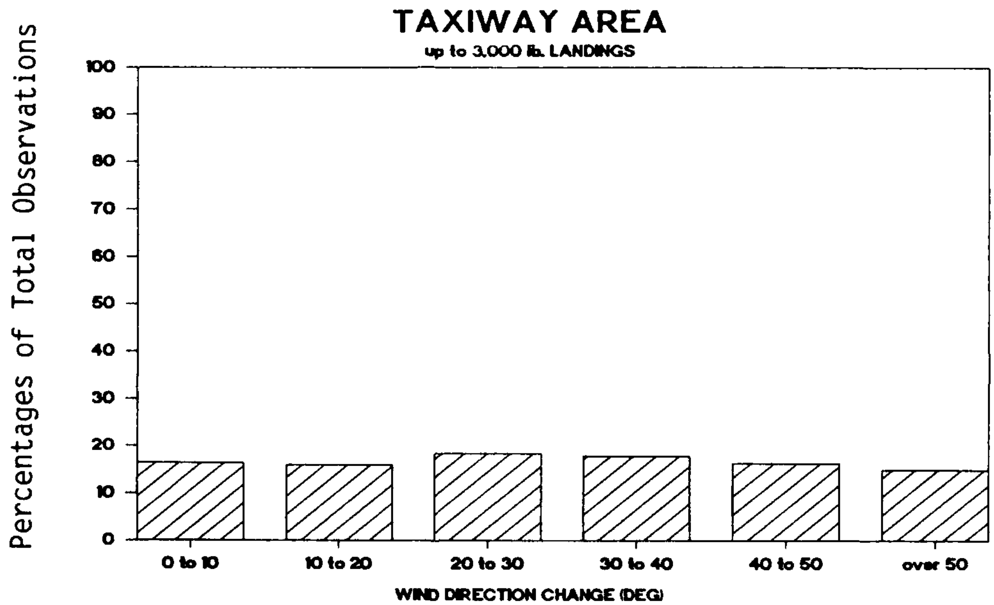


FIGURE 14. HISTOGRAMS OF WIND VELOCITY CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 3 OF 3)





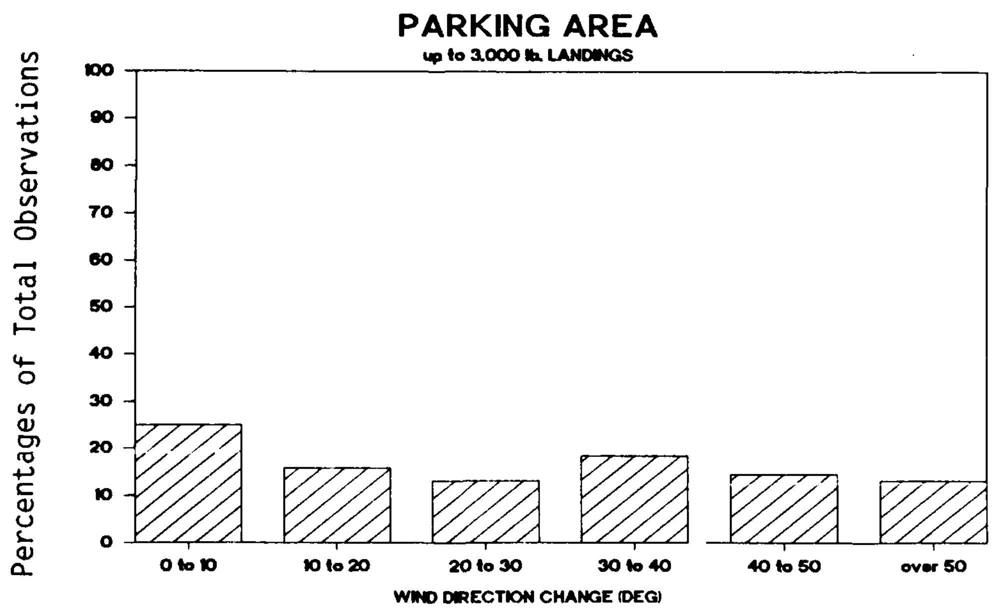


FIGURE 15. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 1 OF 3)

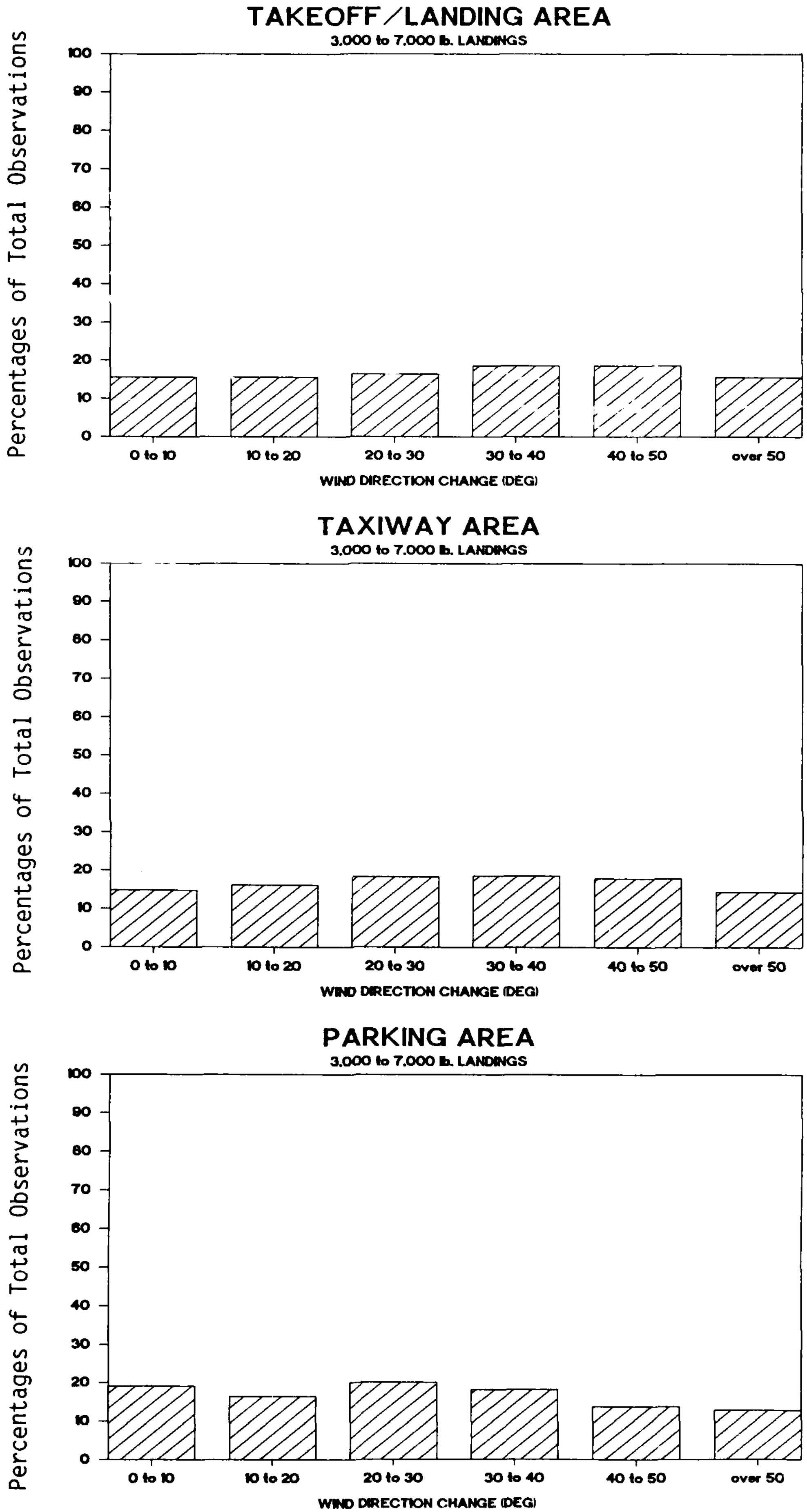


FIGURE 15. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 2 OF 3)

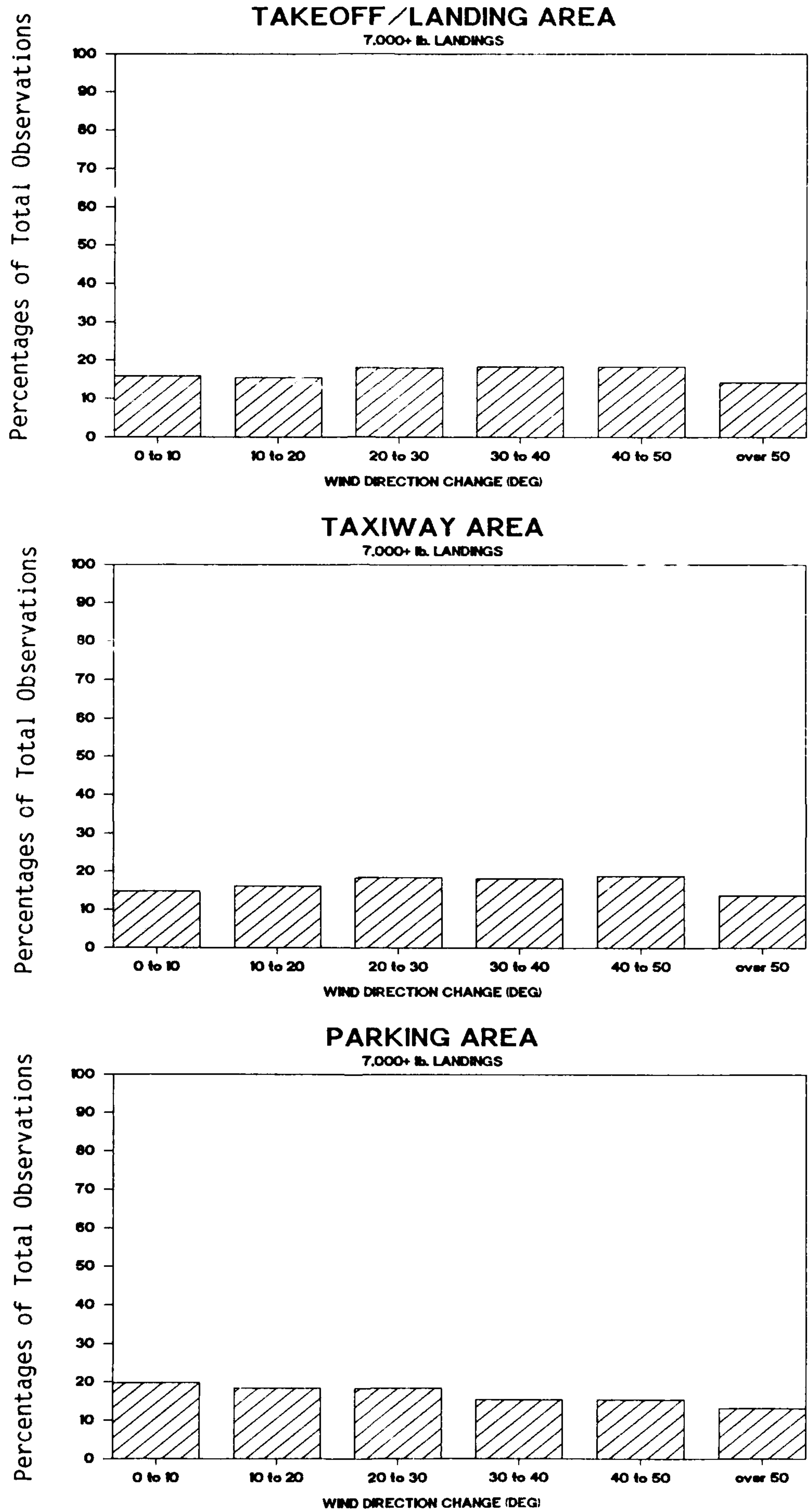
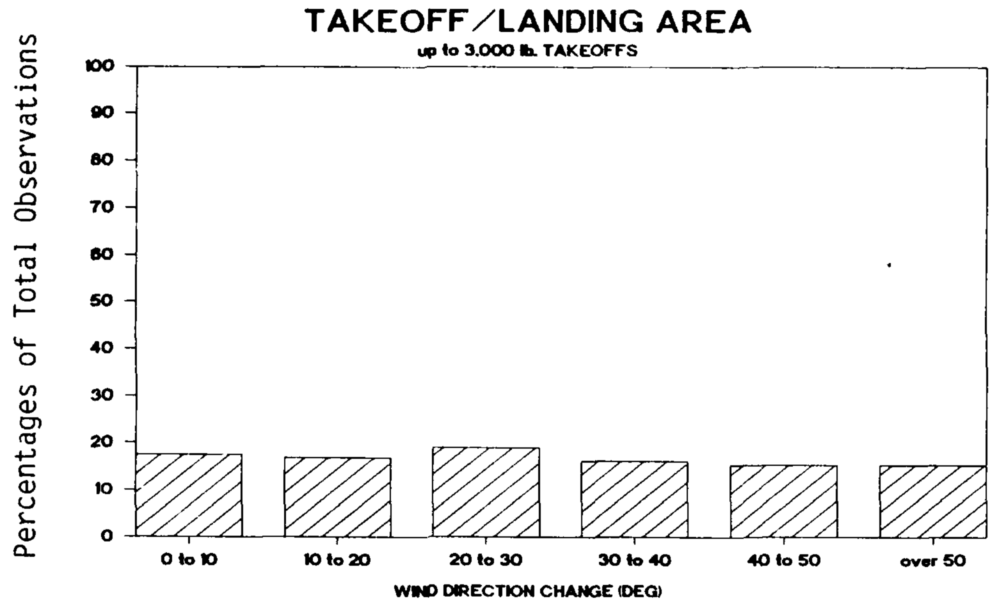
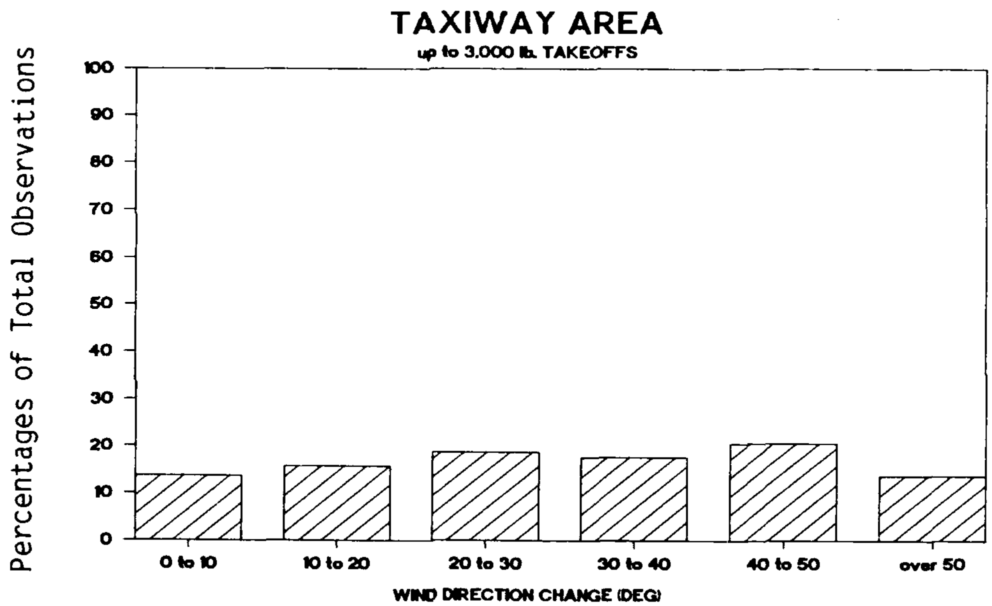


FIGURE 15. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT APPROACHES (SHEET 3 OF 3)





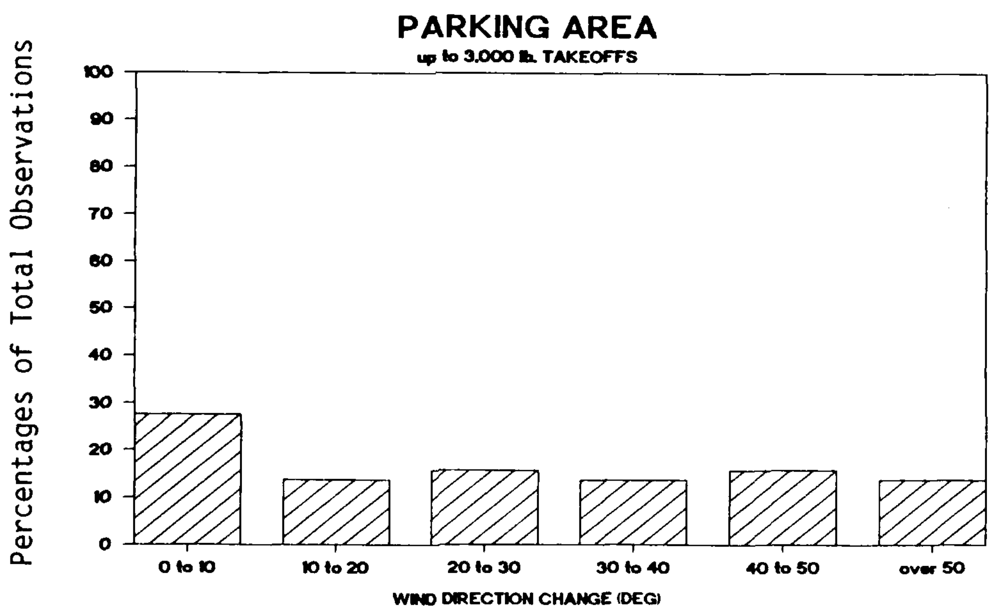


FIGURE 16. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 1 OF 3)

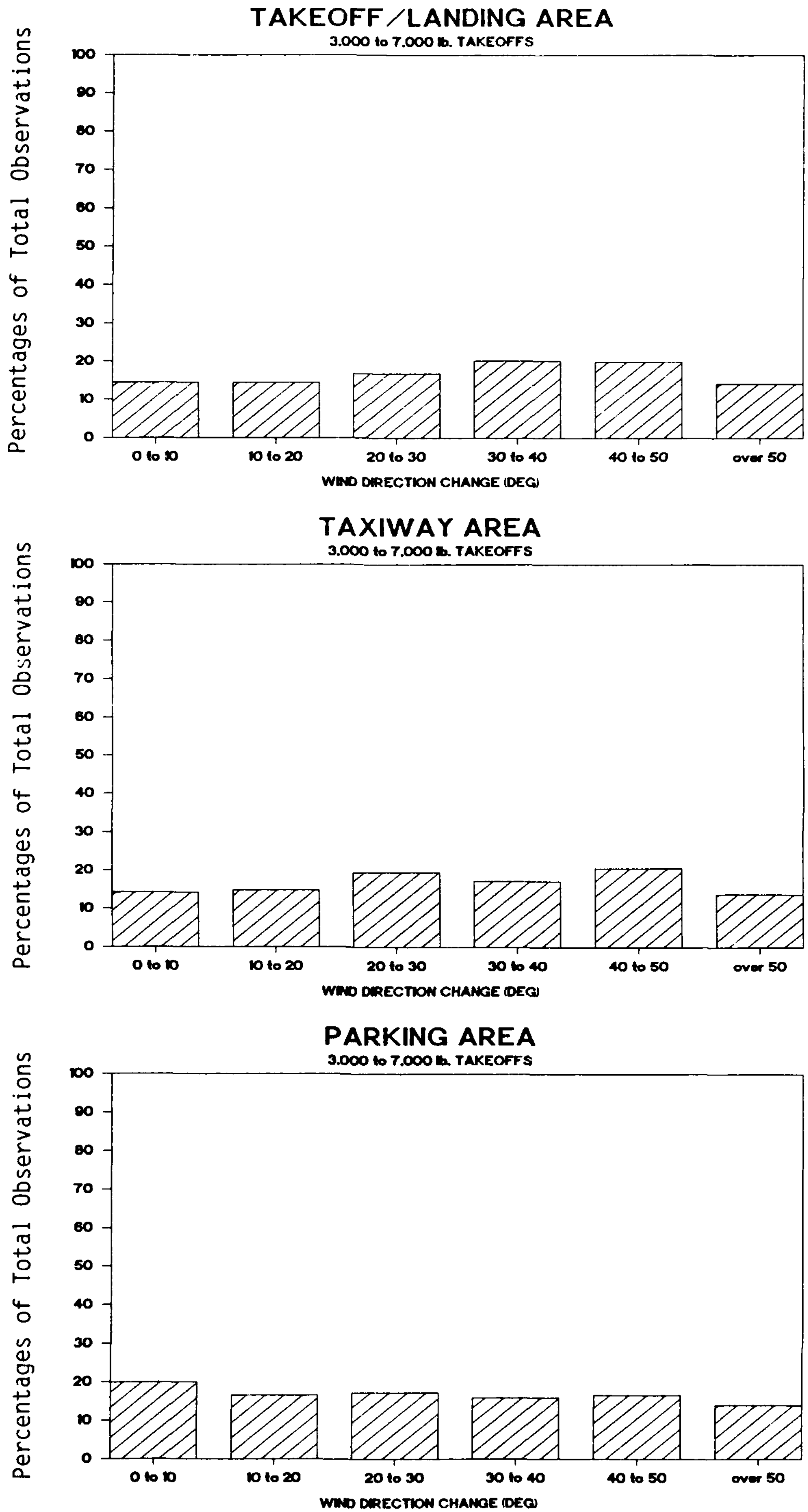
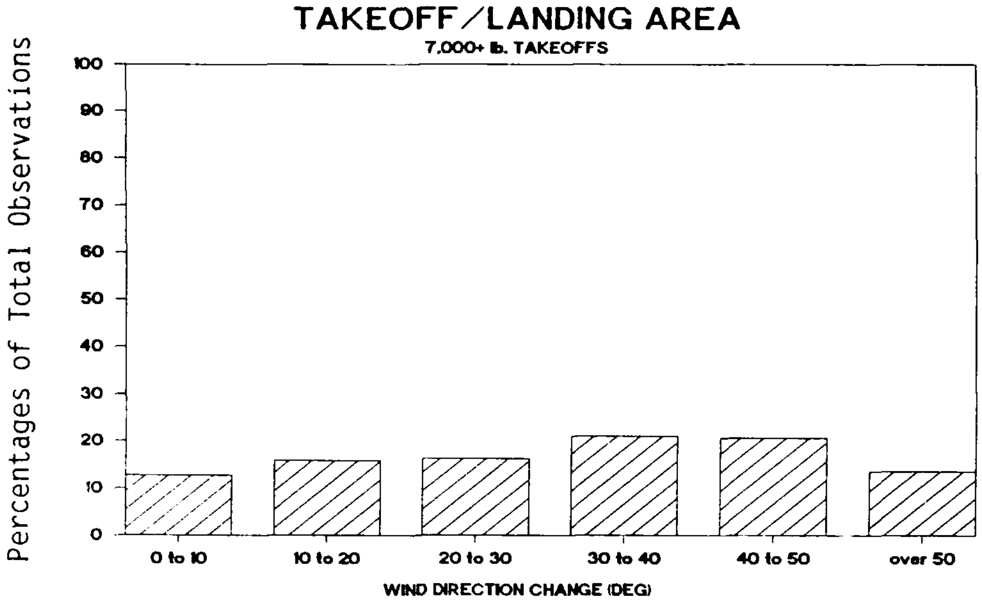
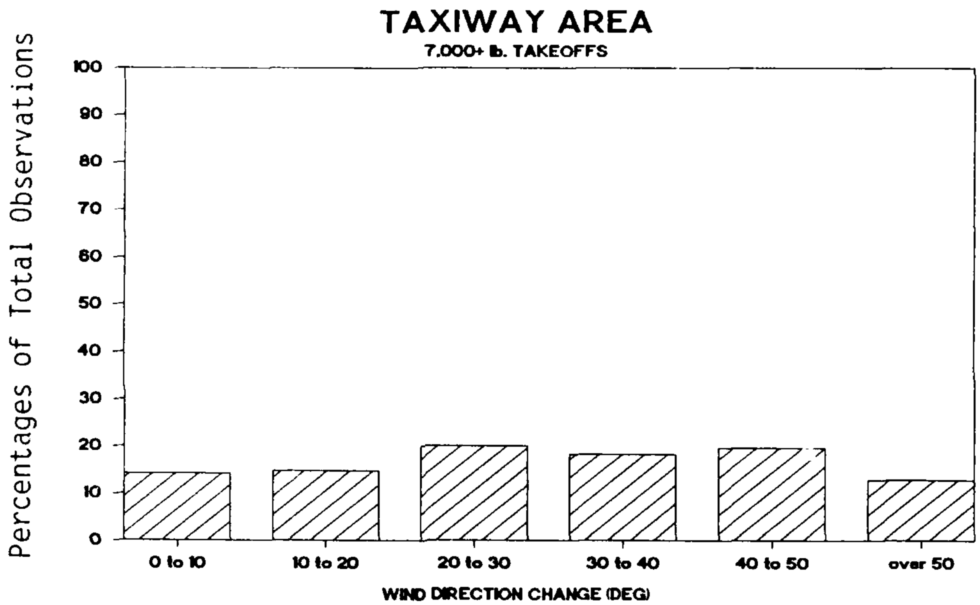


FIGURE 16. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 2 OF 3)





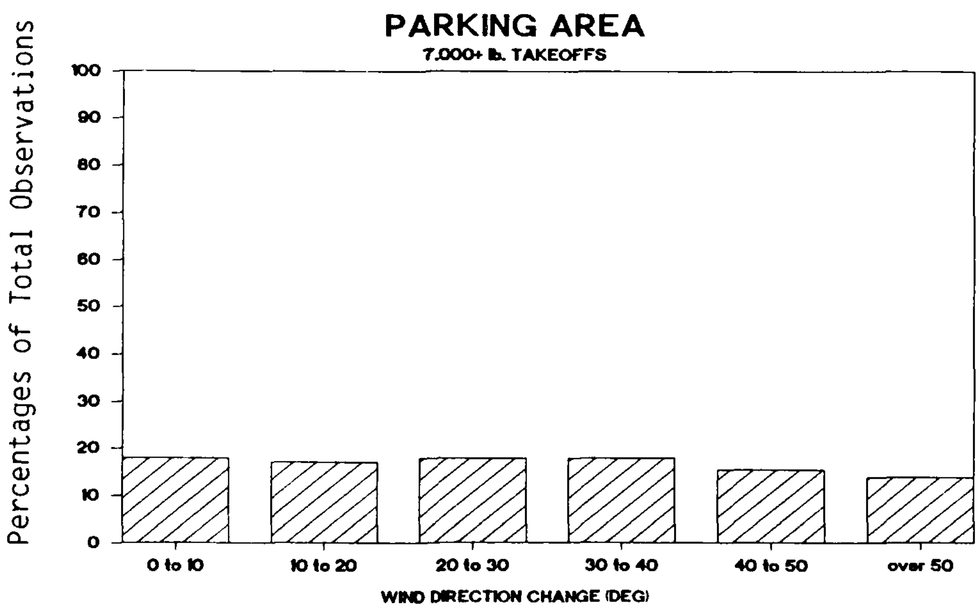


FIGURE 16. HISTOGRAMS OF WIND DIRECTION CHANGES FOR THE INDIANAPOLIS DOWNTOWN HELIPORT DEPARTURES (SHEET 3 OF 3)

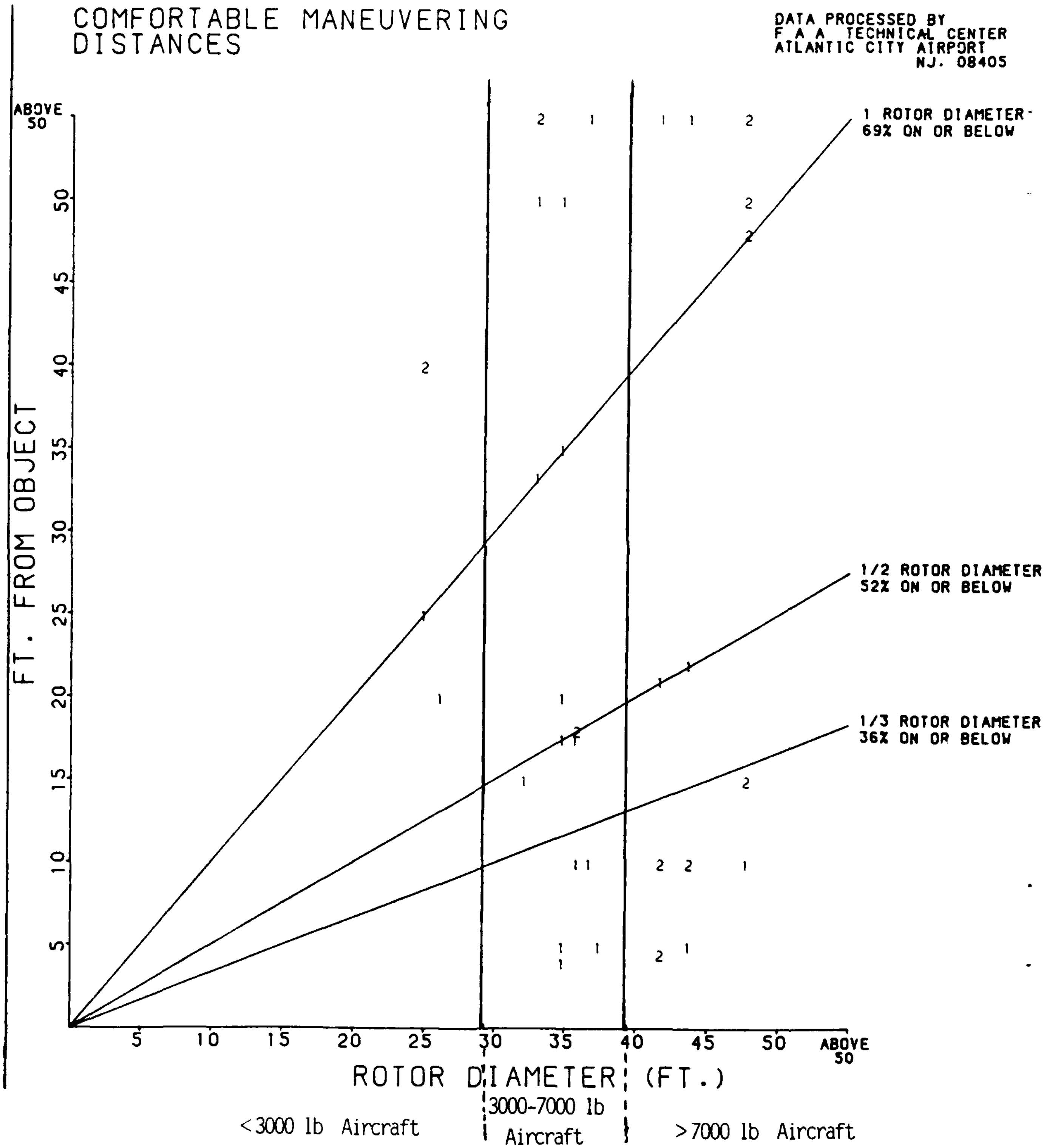


FIGURE 17. PLOTS OF PILOT RESPONSES: COMFORTABLE MANEUVERING DISTANCES - OBJECTS

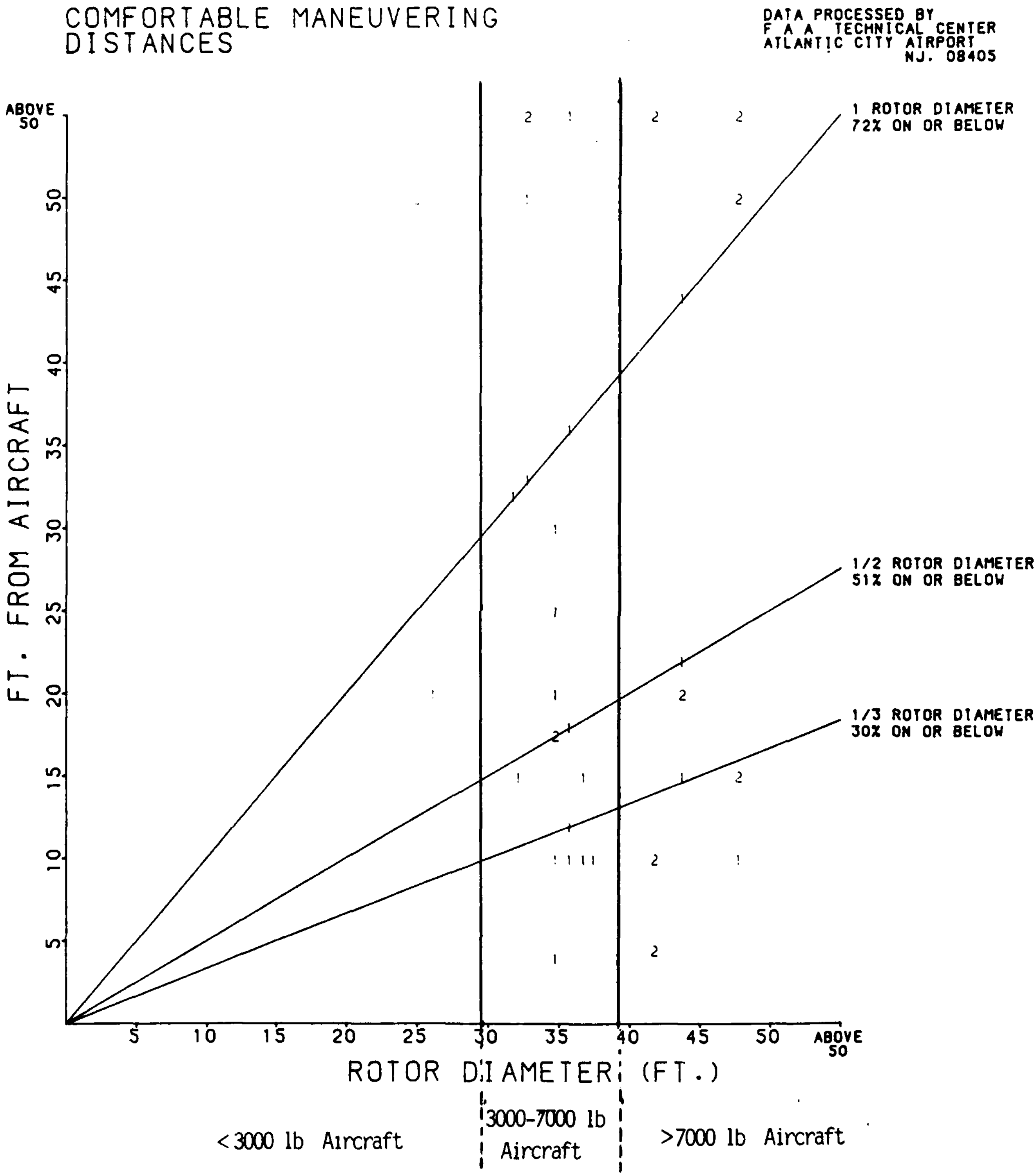


FIGURE 18. PLOTS OF PILOT RESPONSES: COMFORTABLE MANEUVERING DISTANCES - AIRCRAFT

APPENDIX A

PHOTOS

LIST OF ILLUSTRATIONS

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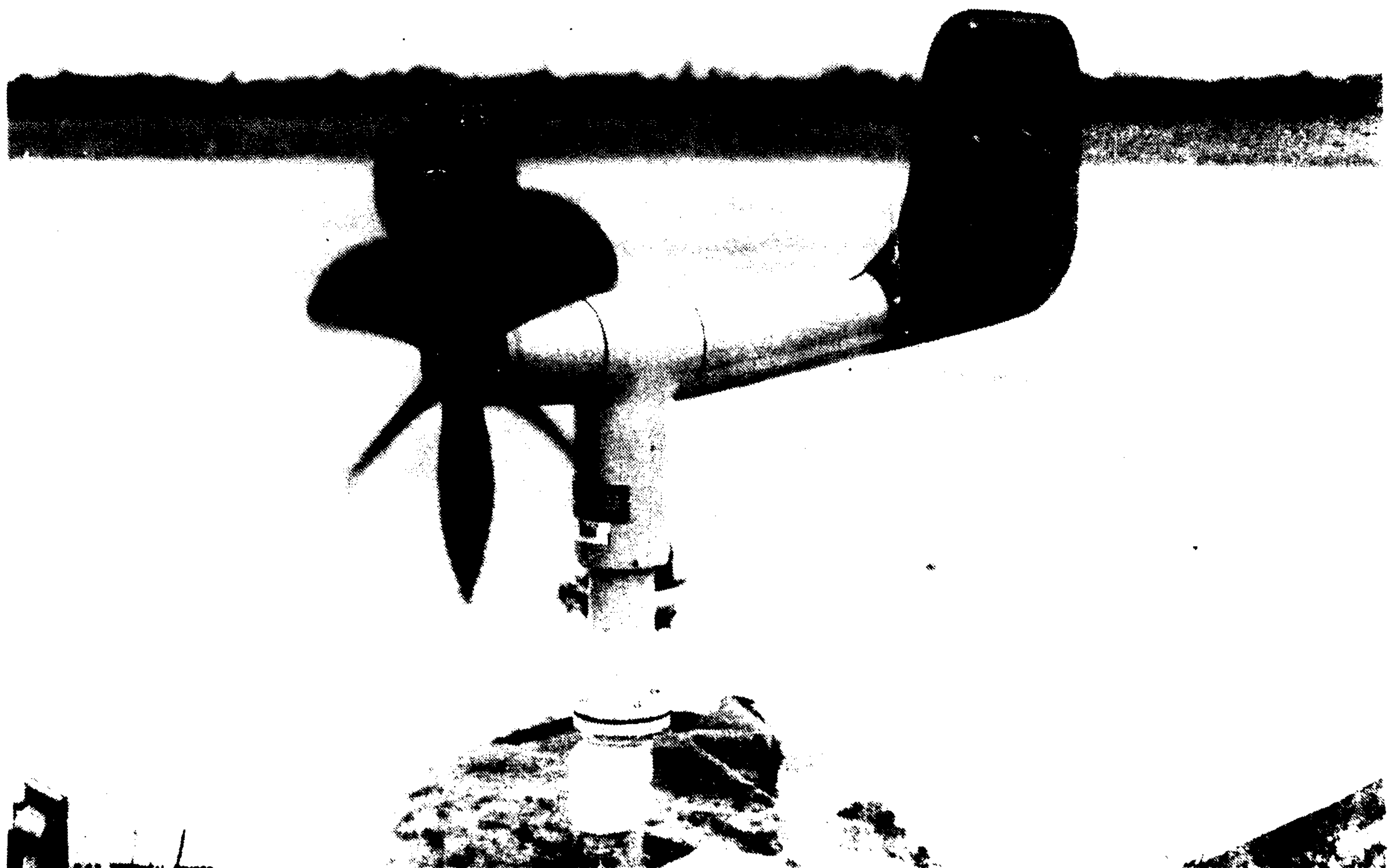

88-0828

FIGURE A-1. CLOSE UP OF A BELFORT INSTRUMENT COMPANY S-122 HD WIND VECTOR TRANSMITTER

FIGURE A-2. LOCATIONS OF 5 OF THE 10 SENSORS USED AT INDIANAPOLIS DOWNTOWN HELIPORT AUGUST 1987

FAA TECHNICAL CENTER ATLANTIC CITY, NEW JERSEY

87-1828

FIGURE A-3. LOCATIONS OF 4 OF THE 10 SENSORS USED AT NEW YORK'S WALL STREET HELIPORT SEPTEMBER 1987